2002

Data acquisition system for die casting processes.

Fang. Chen
University of Windsor

Data Acquisition System for Die Casting Processes

by

Fang Chen

A Thesis
Submitted to the Faculty of Graduate Studies and Research
through Electrical and Computer Engineering
in Partial Fulfillment of the Requirements for
the Degree of Master of Applied Science at the
University of Windsor

Windsor, Ontario, Canada

2002

0-612-75822-2

Abstract

In die-casting processes, molten metal is injected into a die cavity where it solidifies quickly. Proper die temperature control yields a high casting production rate and quality parts. Die temperature is dependent on a number of process variables. It has been found that changes in flow rates of cooling water inside the die affect die temperature; however, very limited research work has been done in this area. In this study, a die casting process simulator has been built in the laboratory. A PC-based data acquisition system (DAS) has been designed, established, and implemented, which is able to acquire, record, and plot temperature and flow rate signals during the die casting process. Experiments have been designed and conducted with the laboratory simulator to assess the heat transfer performance of the die using varying cooling water flow rates with a fixed waterline diameter. In addition to the analysis of experimental data, and process observations, the performance of an air-operated pump, which serves as a control actuator, has been evaluated with consideration of its ability to adjust water flow rates. Finally, the potential for industrial application of the DAS is investigated.

To my parents

Acknowledgements

I would first like to express my sincere thanks to my supervisors Dr. H. Hu and Dr. X. Chen, whose assistance, guidance, and encouragement during this project was a source of continuous inspiration. I would thank Dr. Y. Chu for his insightful guidance. I am grateful to Ryobi Die Casting (USA) Inc for providing funding, donation of the die insert, and privileged technical information.

I would like to express my thanks and appreciation to my committee member Dr. R. Bowers for his time, effort on this thesis, and his invaluable advice. I would also thank my committee member Dr. C. Chen for his time.

I would also like to thank the following individuals for their contributions: Till Kuendiger for his time and comments on the first drafts of this thesis, Patrick Seguin for providing the hardware of the data acquisition system, Idris Elfeghi and Cem Baykal for their input on software design, Andy Jenner and Steve Budinsky for their help in setting up the entire system.

Table of Contents

List of Tables

List of Figures

List of Symbols

c_p	Specific heat of water at constant pressure (J/kg·K)
D	Change in Die Temperature (K)
E	Temperature Error (K)
F	Flow rate (m^3/s)
k	Die thermal conductivity (W/m·K)
$\dot{m}$	Cooling water flow rate by mass (kg/s)
$\dot{q_n}$	Heat flux in direction n (W/m^2)
$\dot{q}_{2,X}(t)$	Instantaneous heat flux across location 2 in X-coordinate direction
$\dot{q}_{3,X}(t)$	Instantaneous heat flux across location 3 in X-coordinate direction
$\dot{q}_{3,Z}(t)$	Instantaneous heat flux across location 3 in Z-coordinate direction
$q_{conv}(t)$	Instantaneous convection heat removal rate (J/s)
R	Resistance to flow ($kg/m^2 \cdot s$)
T	Temperature (K)
$T_o(t)$	Outflow water temperature (K)
$T_i(t)$	Inflow water temperature (K)

T_s	Desired Temperature (K)
$\bar{T}$	Mean value of temperature measurements (K)
T_i	Temperature value (K)
ΔF	Smallest detectable water flow rate (L/min)
ΔP	Pressure difference between tow ends (Pa)
ΔT	Smallest detectable temperature signal (K)
Δ_V	Smallest detectable voltage signal (V)
σ_T	Standard deviation of temperature

Chapter 1

Introduction

1.1 Die Casting Processes

Die casting is a manufacturing process for producing accurately dimensioned, smooth-surface metal components. It is accomplished by forcing molten metal into a reusable metal mould, which is called the die. The process is often described as the shortest distance between raw material and finished product. Typical automotive casting products are engine blocks (see Figure 1-1) and transmission cases (see Figure 1-2). The die is made of two sections to permit easy removal of the finished castings. These two sections are mounted securely in a machine, and arranged so that one is stationary (fixed die half) while the other is movable (injector die half) [1]. Figure 1-3 depicts the schematic view of a die-casting machine.

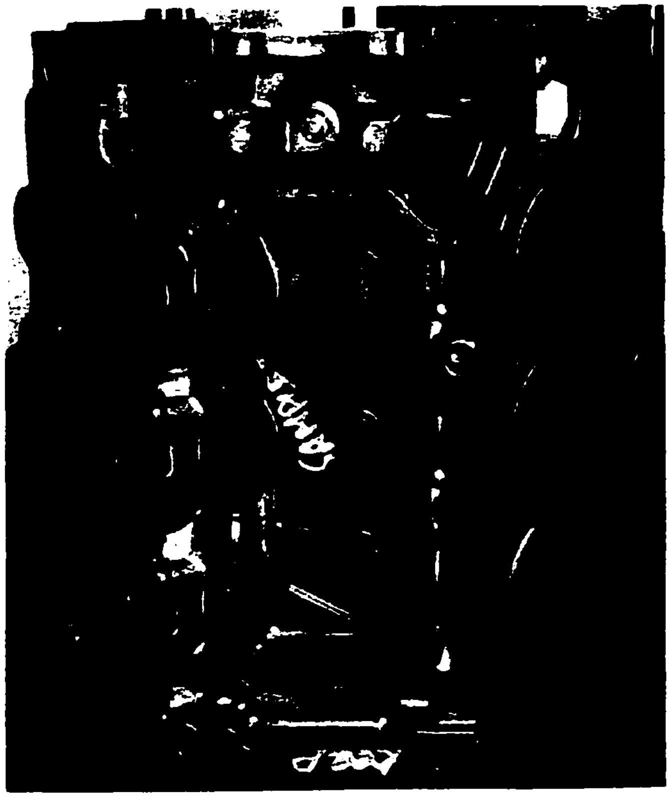


Figure 1-1 Engine Block [2]

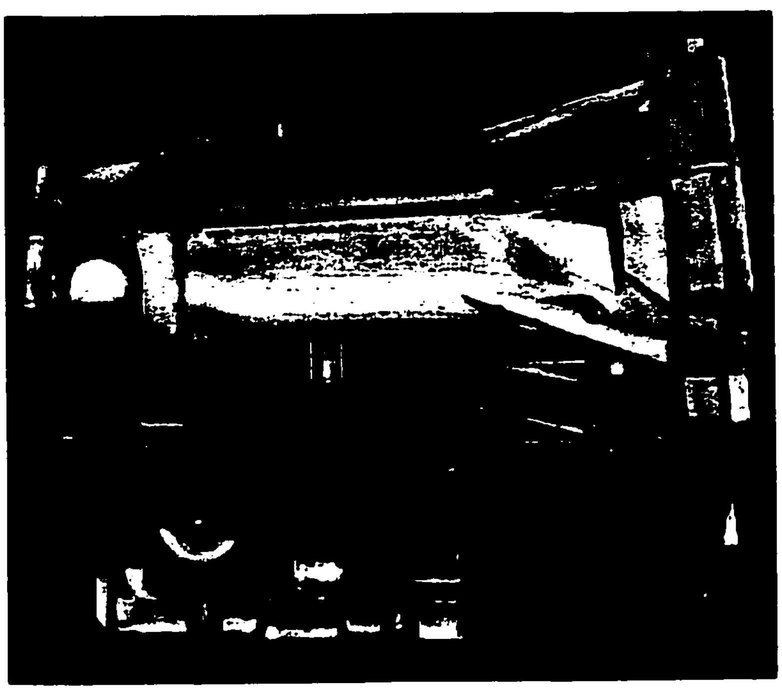


Figure 1-2 Transmission Case [2]

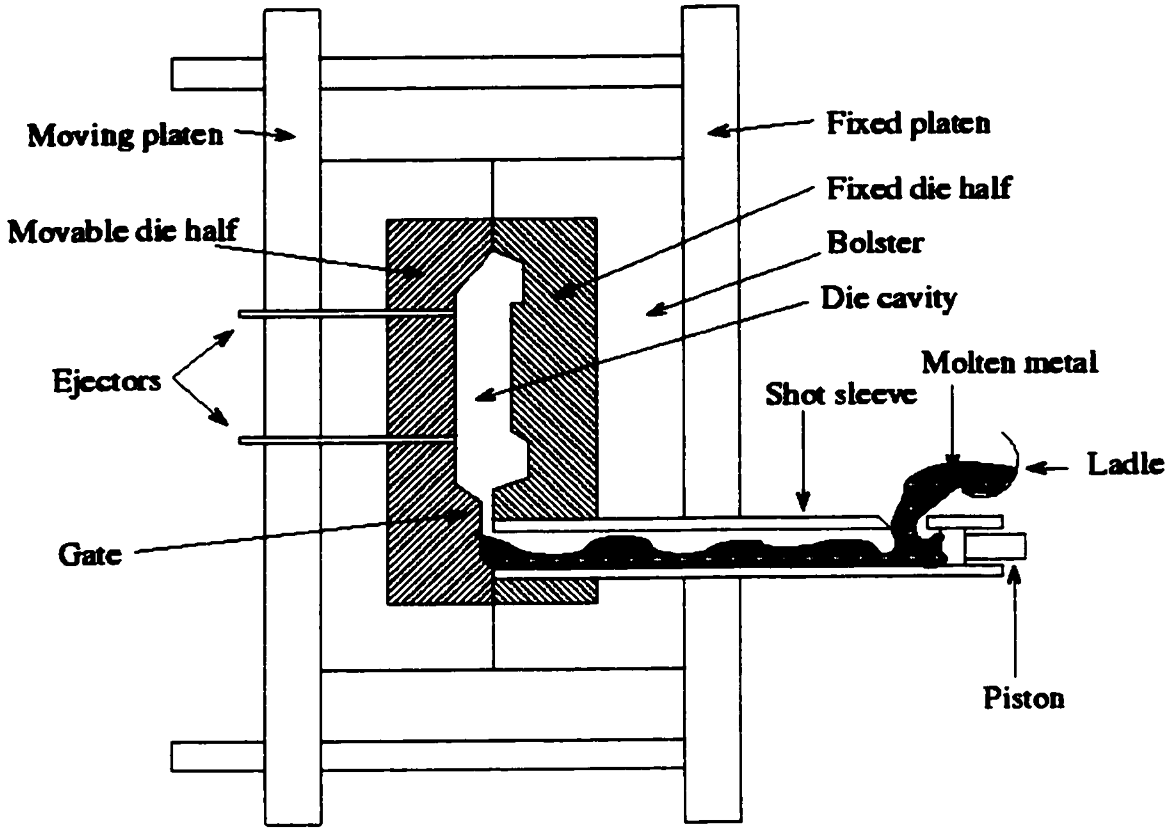


Figure 1-3 Schematic View of Die Casting

To start a casting cycle, the two halves are clamped tightly together by a die casting machine. Molten alloy is injected into the die cavity where it solidifies rapidly. Then, the die halves are separated and the casting is ejected. The die serves two basic functions: to retain the desired shape of the casting, and to remove the heat from the molten metal in a reasonable amount of time. The process is summarized in Figure 1-4.

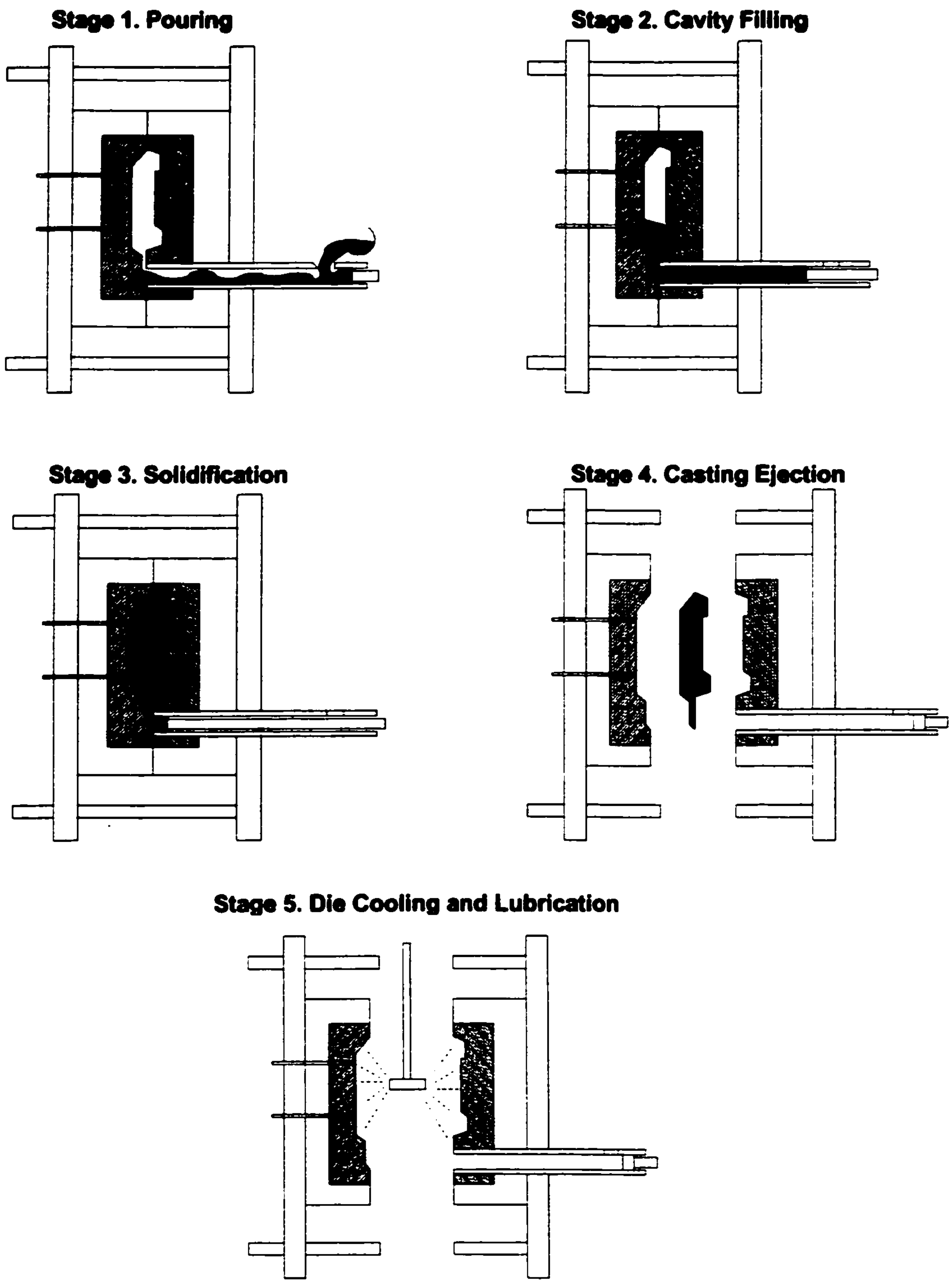


Figure 1-4 Stages of Die Casting Process

During the cavity filling stage, molten metal is poured into the shot sleeve, and then injected into the die cavity by the piston under an applied pressure. The cavity fill time is extremely short, typically between 5 milliseconds and 150 milliseconds depending on casting size. Pressure intensification (10 to over 30 MPa), occurs during the solidification of the metal [1]. The aim of the applied pressure is to reduce the amount of gas porosity and feed shrinkage porosity, as well as to increase the dimensional accuracy of the part. Very often, the die is internally cooled to increase the solidification rate of castings. After solidification, the die opens. The casting is then separated from the die by hydraulic ejector pins, and removed by a robot or an operator. For small aluminum parts, such as bowl casting, in which casting volume is around 0.6 kg, the entire cycle time to produce a single casting can be as short as 25 to 30 seconds [3]. However, the cycle time for larger aluminum castings, such as transmission cases and engine blocks, where the weight is around 10 – 30 kg, may vary from 70 to 180 seconds [2]. The die is usually sprayed with a water-based lubricant at the beginning of each casting cycle.

1.2 Motivation

1.2.1 Real Problem from Ryobi

Ryobi Die Casting (USA) Inc is one of the world's leading die casting manufacturers. Its castings are used for various automotive applications. Engine blocks and transmission cases, which are shown in Figure 1-1 and Figure 1-2, are key products of Ryobi. Due to strong competition within the automotive component market, Ryobi is motivated to further reduce scrap rates by better controlling the thermal pattern of its dies. Figure 1-5 is a picture of a die surface taken by an infrared camera right after a casting was ejected and before the die was sprayed by lubricant. Examination of the thermal image indicates that temperature profile on the die surface varies significantly from 200°C to 400°C. Those die surface zones with relatively high temperatures are less efficient at removing heat from the injected molten metal during the die closing period. The casting, which is illustrated in Figure 1-6, was produced by the pictured die. Studies of the effect of die surface temperature distribution on casting quality have indicated that most of the casting defects, such as porosity and hot tearing, result from such hot spots present in the die [2]. Therefore, Temperature regulation of these critical zones can be used to decrease defects in castings.

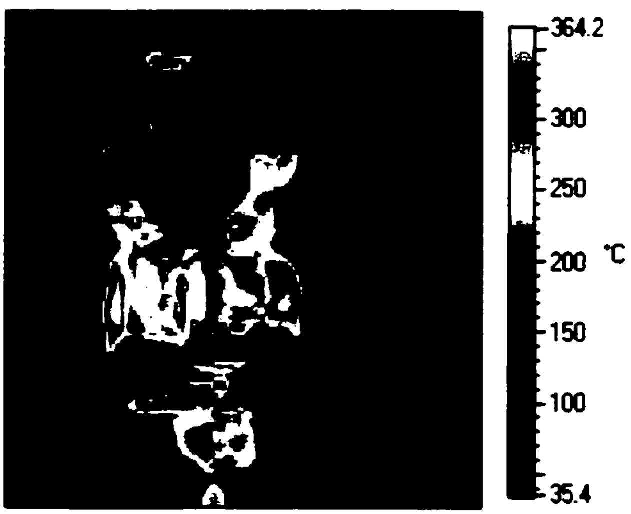


Figure 1-5 Die Surface [2]

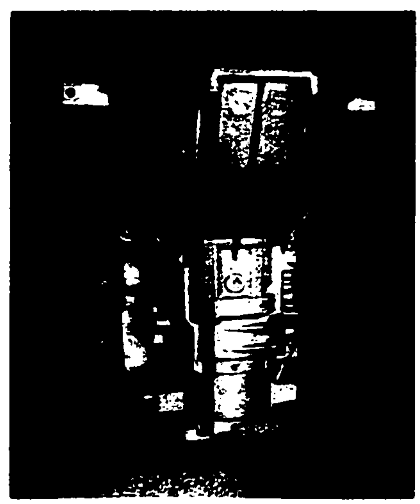


Figure 1-6 Transmission Case [2]

1.2.2 Literature Review

In order to reduce the number of defects in castings, measures must be adopted to reduce temperatures in critical die zones. However, die temperature distribution depends on a number of process variables. In the past, a number of studies have been carried out in an effort to identify and understand the influence of these process variables on die temperature distribution.

Papai and Mobley [3] studied the effect of the initial die surface temperature and the applied casting pressures on die heat absorption. They reported that heat absorbed by the die decreased as the initial surface temperature of the die increased; applied casting pressure had an insignificant influence on heat flux to the die.

Hsieh [4] investigated the effect of change in diameter of waterlines on transient and steady bulk temperatures. He reported that at the same mass flow rate, the time for reaching the steady state became shorter as the diameter of water lines was decreased. He also concluded that the diameter of waterlines had little influence on the steady bulk temperature.

Nelson [5] measured and reported the effect of water flow rate, inlet water temperature, and coolant type on heat removal rates. He observed that the heat removal rate increased with increasing flow rates, and increased as the water temperature decreased for a given flow rate. There was a pronounced decrease in heat removal rate when the ethylene glycol content in the coolant increased.

Thukkaram [6] and Vargo [7] concluded that in order to achieve the desired die temperature gradient, the distance between the surface of the die cavity and the cooling line should be carefully calculated during die design.

1.3 Methodology

As mentioned earlier, one complete metal mould (die) consists of two sections, the movable die half and the fixed die half. Each die half consists of many die inserts. Each die insert has at least one internal cooling waterline. Figure 1-7 shows a die insert with one internal cooling waterline.

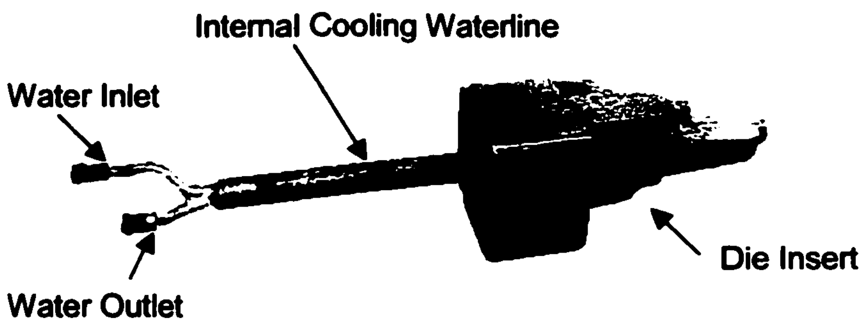


Figure 1-7 Die Insert with Internal Cooling Waterline

Establishment of a reliable relation between cooling water flow rates and heat removal rates requires numerous experiments; however, these experiments are costly to conduct on real die casting machines. Instead, a die casting process lab simulator was built. A die insert (see Figure 1-7) was donated by Ryobi, and a 3kW furnace was used to heat the die insert. As will be addressed in Chapter 2, the simulator was used to simulate die casting processes. A data acquisition system dedicated to die casting processes also has been developed, and was used to conduct experiments in conjunction with the lab simulator.

1.4 Thesis Organization

This thesis is divided into eight chapters. Chapter one provides background information about die casting processes, and discusses problems existing in die casting industry. Research methodology is also presented.

Chapter two presents the setup of the die casting process simulator, including hardware and procedures. It compares the simulator to real die casting processes in several aspects.

Chapter three is devoted to the design and implementation of a PC-based data acquisition system (DAS). It gives the details of DAS hardware and software. Also, the performance of the data acquisition system is evaluated.

Chapter four discusses the experimental design and procedures. Three experimental setups are designed for different experimental objectives.

Chapter five presents the experimental data. Data analysis and discussion for the three different experimental setups are also presented.

Chapter six is devoted to discussion of a control system. It describes the steps of designing a fuzzy logic die temperature controller, and proposes the guidelines on how to integrate a fuzzy logic controller to the existing data acquisition system.

Chapter seven presents a summary of the work carried out, and conclusions based on experimental data observations.

Chapter eight completes this thesis with some recommendations arising from the present work.

Chapter 2

Die Casting Process Simulator

2.1 Simulator Setup

The purpose for building a die casting process simulator is to provide an experimental setup, which is similar to the actual die casting process to conduct representative experiments. Die casting process simulator includes hardware setup and procedure setup.

2.1.1 Hardware Setup

One die insert made of H13 tool steel (Appendix C) with an internal cooling waterline from Ryobi Die Casting (USA) Inc is used in the simulator. Instead of heating the die by directly pouring molten aluminum alloy onto it, a 3kW furnace is used to preheat the die insert to a certain temperature. The piece of the insert is mounted to a movable rack that supports the insert. An insulating plate is placed between the contact surface of the insert and the metal rack.

The insert is pushed into the furnace until it is completely enclosed by the furnace (see Figure 2-1).

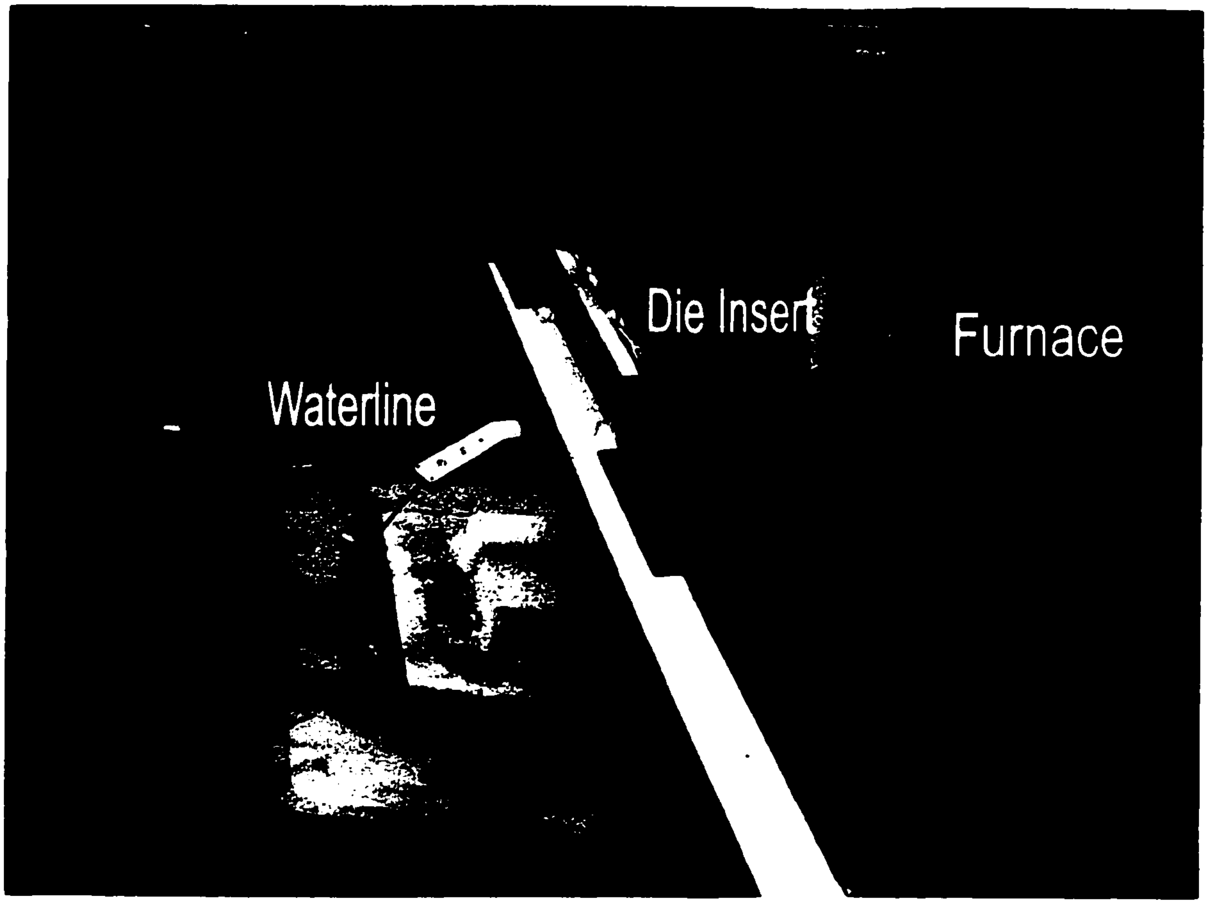


Figure 2-1 Simulator Hardware Setup

2.1.2 Procedure Setup

Two stages are involved in the lab simulator: furnace preheating and insert cooling. The furnace temperature is set at 800°C during the die heating stage in order to shorten the preheat time. When the die insert reaches 550°C at location 1 (shown in Figure 2-2), the furnace is turned off and the cooling stage starts. Water is supplied to the internal waterline. The insert is still kept in the furnace during cooling stage. The die casting process simulator is schematically shown in Figure 2-2.

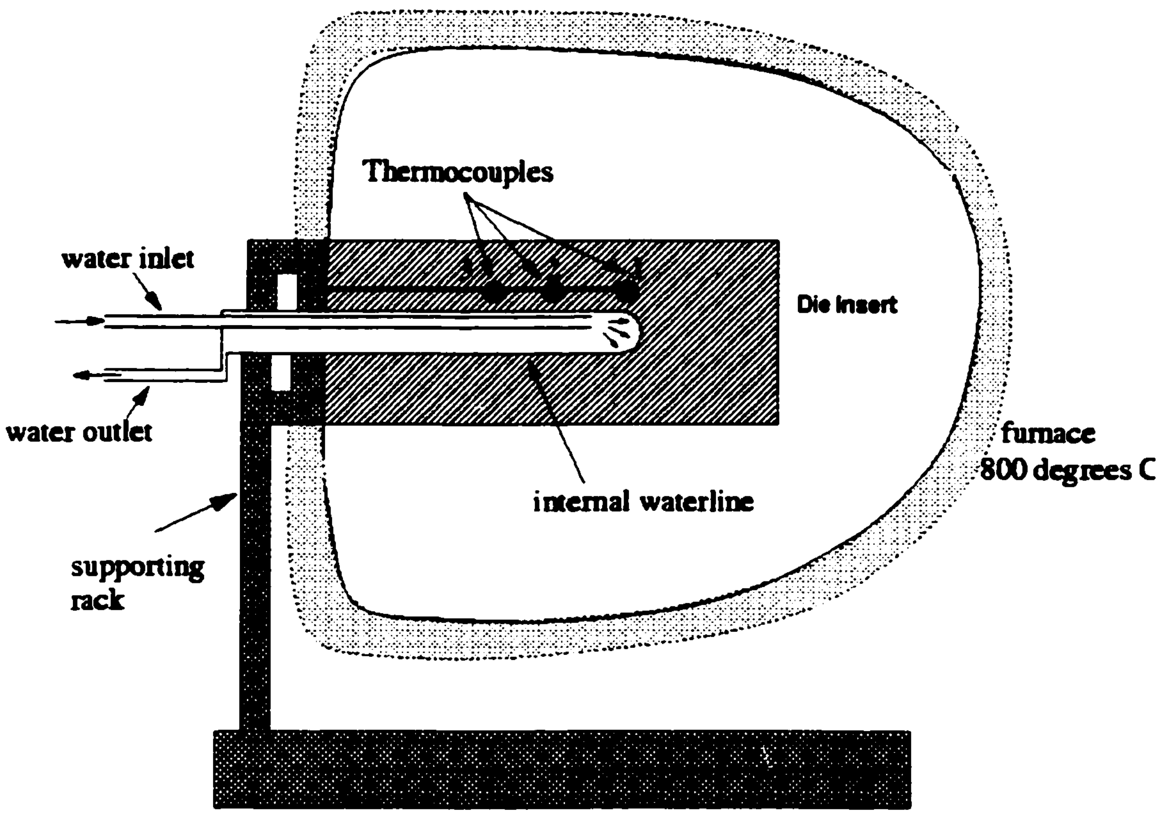


Figure 2-2 Schematic of Die-Casting Process Simulator

2.2 Die Casting Processes

In real die casting processes, three main stages are included in one complete cycle: cavity filling, solidification and casting ejection. Figure 2-3 shows the variation of die surface temperature for a complete die casting cycle of 380 Aluminum alloy bowl determined by J. Papai and C. Mobley [3].

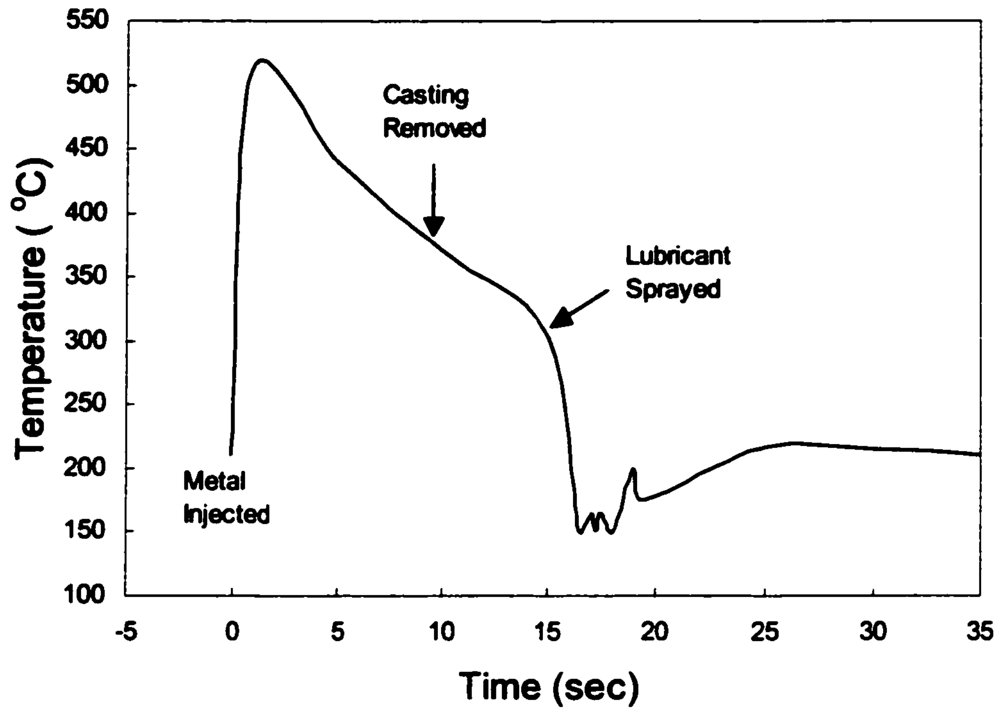


Figure 2-3 Temperature of Die in One Casting Cycle [3]

In their experiments, the total casting weight was 0.794kg. Die closing time was about 10 seconds. During the die closing stage, cavity filling and solidification occurred. According to Figure 2-3, the die temperature reached the maximum at 510°C in less than 1 second then decreased. The heat was removed from the die primarily by an internal cooling waterline during the die closing stage, which allowed molten aluminum to solidify. The casting bowl was removed once the die was opened. The die surface was sprayed with lubricant for 2 to 4 seconds. The total die open time was 25 to 30 seconds. Then the next cycle started and repeated the above steps.

2.3 Comparison

Table 2-1 compares the experimental procedures of the lab simulator to the real die casting processes for producing automotive components

Table 2-1 Comparison of Real Die Casting Process with Simulator

	[illegible]	[illegible]
[illegible]	Molten metal injected	Die preheated by furnace
[illegible]	1-5 Seconds	90 minutes
[illegible]	Internal waterline	Internal waterline
[illegible]	Lubricant spray	None
[illegible]	Cavity filling, Solidification,Casting ejection, Lubricant spray	Insert preheating, Insert cooling
[illegible]	Multiple pieces of die inserts	One piece of die insert
[illegible]	H13 tool steel	H13 tool steel

2.4 Experimental Consideration

The present study is focused on how the internal temperature of the die insert changes, and how heat removal rates change with the variation of internal cooling water flow rates during the die closing stage. During this stage, internal cooling water plays the primary role of removing heat from the die. During the insert cooling stage the internal waterline removes the most heat just as it does during the solidification stage in a real die casting process. Therefore, the die insert cooling stage is employed to simulate the solidification stage. Experiments were designed to discover how water flow rate affects the heat removal rate and the die internal temperature. Hence, experimental results can be employed to provide a numerical guideline for designing a die temperature controller.

2.5 Summary

This chapter has provided the details about the hardware and procedure setup of a die casting process simulator, which has been built in the laboratory. Actual die casting processes have been reviewed, and comparisons between the lab simulator and the real die casting process have been discussed. It has been concluded that the die cooling stage can be employed to simulate the solidification stage of the real die casting processes.

Chapter 3

Data Acquisition System (DAS) for Die Casting Processes

3.1 Introduction to DAS

A system that collects information is called a data acquisition system (DAS). There are two major types of data acquisition system: PC-based DAS and stand-alone DAS. A PC-based system uses plug-in data acquisition card that is plugged directly into a computer. Signals from sensors or signal conditioners are wired to the computer and connected to the data acquisition board. A stand-alone system is self-contained Input/Output system. It acquires data in the field, and sends it to the computer via a communication method. Even though stand-alone data acquisition systems have more capability and flexibility, PC-based systems represent the most efficient and most economical solution to many data acquisition applications.

A PC-based data acquisition and control system typically consists of seven main components [9]: sensors, signal conditioning, Analog/Digital (A/D) converter, computer, output interface, and actuator. The diagram of a PC-based system is shown in Figure 3-1.

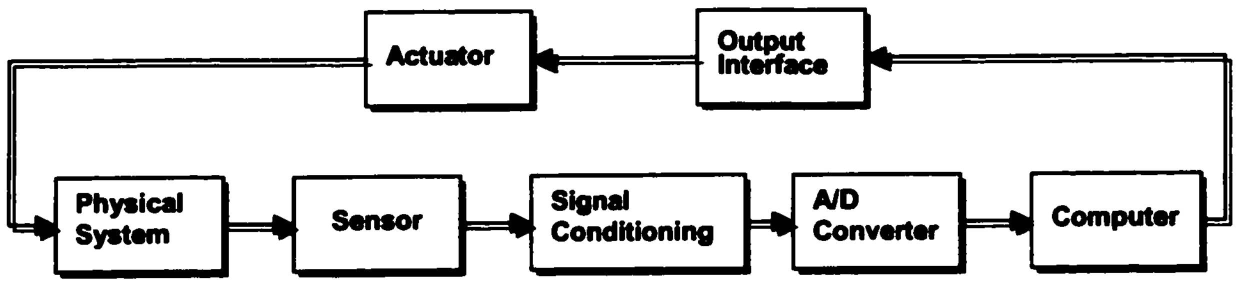


Figure 3-1 PC-based Data Acquisition and Control System

The Sensor measure physical variable, such as temperature, pressure, flow rate, motion, and convert it to electric signal. The Signal conditioning amplifies and filters the sensor signal, then outputs a voltage that can be read by the A/D converter. The A/D converter converts analog signals into digital format usable by computer. The computer acquires data, and sends a control signal to the actuator. An output interface is necessary if the format of the control signal does not match the format required by the actuator. The actuator changes the control system commands into driving forces that are applied to the physical plant.

3.2 DAS Design

3.2.1 System Requirements

The system had to be able to measure three-channel temperature signals from three thermocouples and one-channel water flow rate signal from water meter. For the temperature signal, the desired measurement range is from 0 °C to 600 °C, and the desired resolution is 1°C. For the water flow rate signal, the desired measurement range is from 2.08 L/min (0.55GPM) to 9.46L/min (2.5GPM) with a resolution of 0.0379 L/min (0.01GPM).

3.2.2 Selection and Design of DAS Hardware

Temperature Sensor

Temperature can be measured via a diverse array of sensors. Three types of temperature sensors are most commonly used in lab and industrial applications: thermocouples, resistance temperature devices (RTD), and infrared sensors [10]. A brief view of each type of temperature sensor is presented below.

Thermocouples consist essentially of two strips or wires made of different metals and joined at one end. Changes in the temperature at that juncture induce a change in electromotive force (emf) between the other ends. As the closed-end temperature T_1 (the temperature at the point of measurement) goes up, the output emf V_1 at the open-end of the thermocouple (see Figure 3-2) rises. The open-end emf V_1 is also the function of the temperature T_2 at the open end. Only by holding T_2 at a standard temperature, the measured emf V_1 can be considered a direct function of the change in T_1. The industrially accepted standard for T_2 is 0°C. In industrial instrumentation, the difference between the actual temperature T_2 and 0°C is usually corrected electronically in the instrumentation. This emf adjustment is referred to as the cold-junction compensation.

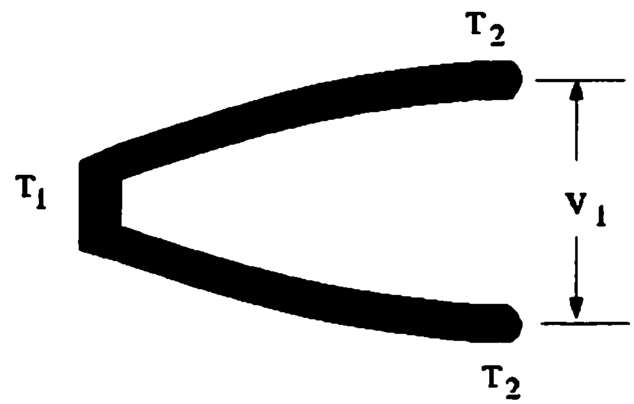


Figure 3-2 Thermocouple's Mechanism

There are 9 different types of thermocouples according to the metals used. Most commonly used types in industry are Type K and Type J. Figure 3-3 is drawn according to the thermocouple reference table revised by National Institute of Standards and Technology (NIST) of United States. It shows the thermoelectric voltage output of Type K thermocouple when reference junction is at 0°C. According to Figure 3-3, the thermoelectric output of Type K is approximately linear with the temperature in the range from 0°C to 600°C.

Type K thermocouple usually operates from -200°C to 1,250°C. Standard error limits are 2.2°C or 0.75% whichever is greater. Special thermocouples can be made with limits error of 1.1°C or 0.4% whichever is greater.

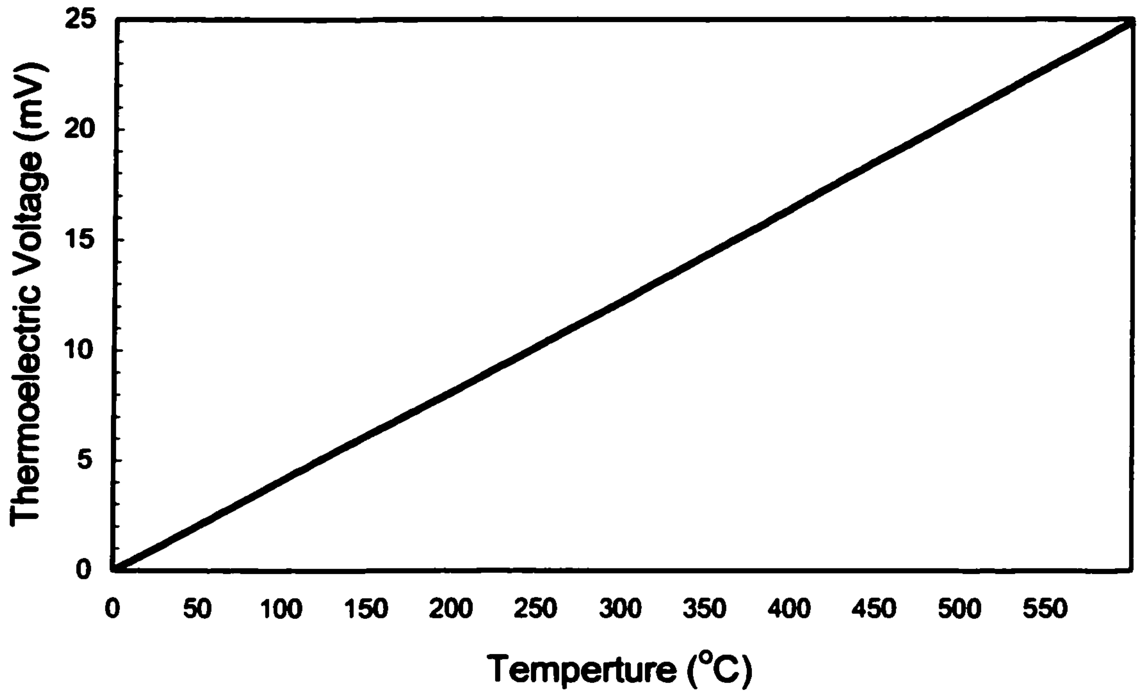


Figure 3-3 Characteristics of Type K Thermocouple

Resistance temperature devices (RTD) capitalize on the fact that the electrical resistance of a material changes as its temperature changes. RTDs operate in the range from about -250°C to 850°C with the resistance rising more or less linearly with temperature.

Infrared sensors are non-contacting devices. They infer temperature by measuring the thermal radiation emitted by a material. They are used for cases when the temperatures are extremely high, e.g.3000°C, far exceeding the range of thermocouples; no contact with the surface is required to measure temperature.

Comparing three types of temperature sensors, thermocouples generally can measure temperatures over wide temperature ranges inexpensively and are very rugged; they are not, however, as accurate as RTD's.

OMEGA low noise thermocouple probes (see Figure 3-4), model number HUKMQSS, have been selected as temperature sensors for the system. This type of thermocouple has ground strap connection that provides protection against electrical noise and is made with special limits of error material that ensures high accuracy measurement.

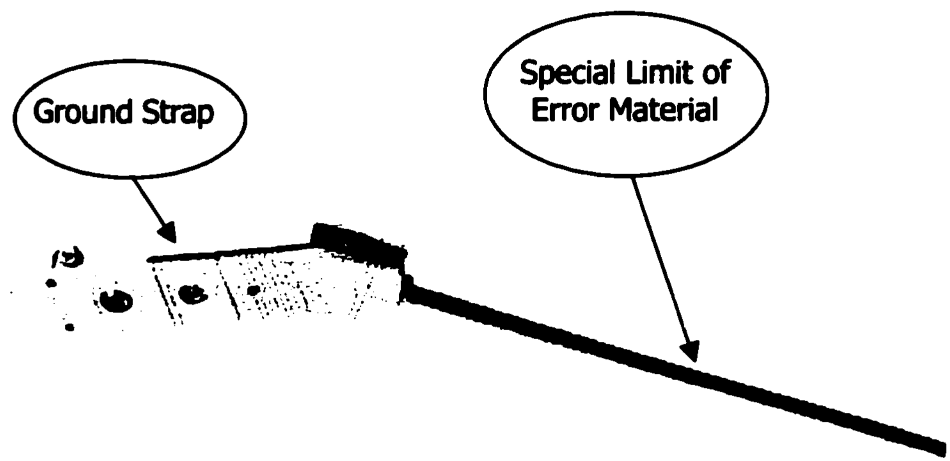


Figure 3-4 Thermocouple HUKMQSS

Temperature Signal Conditioning

The output signal of the thermocouple is too low to be read directly by the data acquisition board. For example, according to thermocouple reference tables, at 600°C the output of Type K thermocouple is 24.906mV. If no amplification was applied to the output signal, the smallest temperature that a 12-bit data acquisition board with an analog input range from 0 Volts to 5 Volts can detect is 30°C, which is unacceptable. The output signal of a thermocouple is also very noisy. Noise is induced along the path of the signal wires, as well as there being noise at the signal source itself. Signal conditioning is necessary in order to amplify and filter the thermocouple signals.

OMEGA Thermocouple D.C. Millivolt Amplifier (see Figure 3-5), model number Omni-Amp IIB, has been selected as the temperature signal conditioner. It has a built-in cold junction compensation, amplifier, and filer. The maximum output to input signal gain of the Omin-Amp is 100.

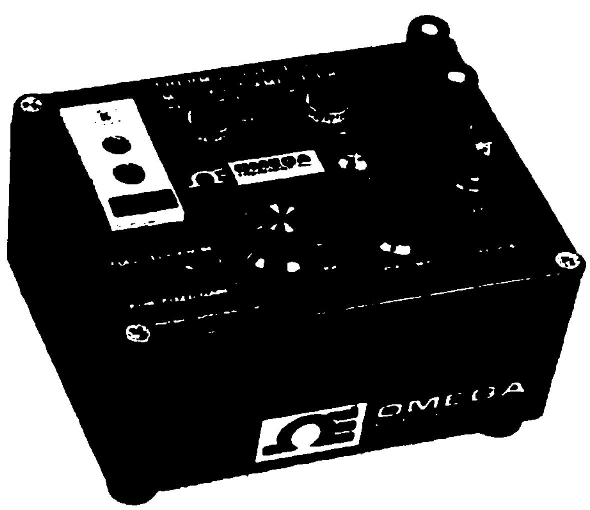


Figure 3-5 Thermocouple Conditioner: Omni-Amp IIB

Water Flow Rate Sensor

The RotoFlow flow sensor (see Figure 3-6) manufactured by Gems Sensors Inc. has been selected as a water flow meter to measure the cooling water flow rate in die insert. The output of the meter is 0 to 10VDC corresponding to the flow rate 2.08L/min (0.55GPM) to 18.9L/min (5GPM). This level signal can be read directly by the data acquisition board and no signal amplifier is needed. The output signal curve of the water flow meter is shown in Figure 3-7.

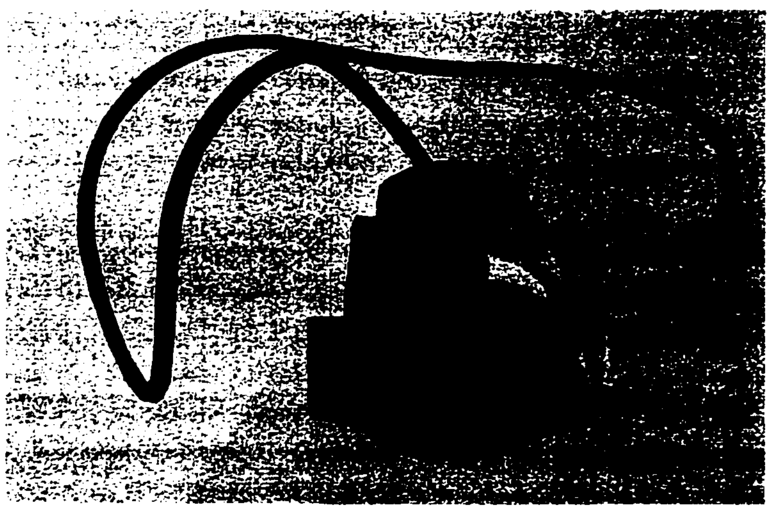


Figure 3-6 Water Flow Meter

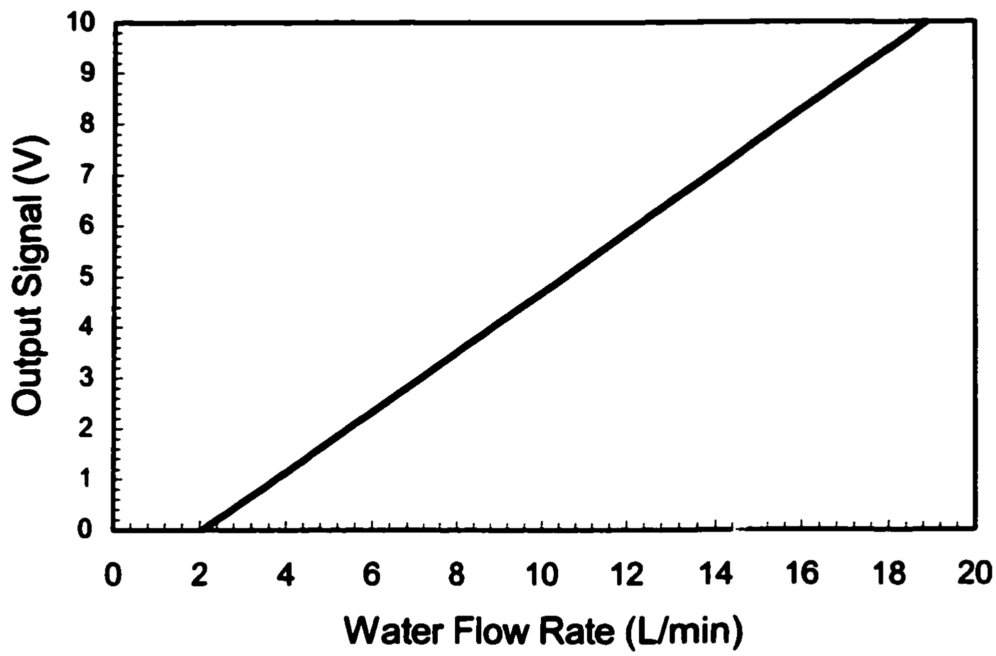


Figure 3-7 Characteristics of the Water Flow Meter

Data Acquisition Board

The primary concerns when selecting a plug-in data acquisition board are resolution, number of input channels, maximum sampling rate, and output functionality. The Cyberresearch 12-bit data acquisition board with 8-channel differential inputs (see Figure 3-8), Part #CYDAS 1602DAP, met the system requirements.

Figure 3-8 Data Acquisition Board 1602DAP

For the 12-bit data acquisition board with an input range from 0 to 10 V, the smallest voltage Δ_V detectable is determined by following equation:

$$\Delta_V = \frac{10}{2^{12}} = \frac{10}{4096} = 2.44\text{mV} \qquad (3\text{-}1)$$

If the amplifier gain is set at 100, when measurement point reaches 600°C, the output of signal conditioner is 2.49V. The smallest temperature ΔT that can be detected by the data acquisition board is then calculated by:

$$\Delta T = \frac{600°C}{2.49 \times 10^3 mV} \times 2.44 mV = 0.6°\text{C} \qquad (3\text{-}2)$$

The smallest detectable water flow rate ΔF is calculated by:

$$\Delta F = \frac{5GPM}{10\times10^3 mV} \times 2.44mV = 0.004\ 62\ \text{L/min} \qquad (3\text{-}3)$$

Specifications for data acquisition board 1602DAP are summarized in Table 3-1.

Table 3-1 Specification of 1602DAP

[illegible]	Resolution	12 bits
	On-Board Memory Buffer	1024 Samples
[illegible]	Single-Ended	16
	Differential	8
Speed	A/D Converter Speed	3 μs
	Maximum Sample Rate	330kHz
Input Ranges	Software-Selectable Ranges	Y
	Unipolar Inputs	0-10V
	Bipolar Inputs	$\pm$10V
	Gains	1, 2, 4, 8
Trigger Modes	Pre-trigger	Y
	Analog Slope	Y
	External Pulse	Y
	Software-Selectable Ranges	Y
	Counter/Timer	Y
CMRR	Common Mode Rejection Ratio	70dB
Analog Outputs	Number of D/A Channels	2
	D/A Resolution	12 bits
	Unipolar D/A Ranges	0-5, 10V
	Bipolar D/A Ranges	$\pm$5,10 V
	D/A Range Selection	Software
	D/A Conversion Speed	200kHz
Digital I/O	Number of Digital I/O Lines	2x8-bit 2x4-bit
	Input/Output Selection	Software
	Output Current Sink	2.5mA

Pump

A Wilden air-operated water pump is selected as an actuator; it can be controlled by an electrical signal to increase water flow rate up to 9.46 L/min (2.5GPM). Through changing the pump speed, which is denoted as stroke per minute (SPM), the flow rate is changed accordingly.

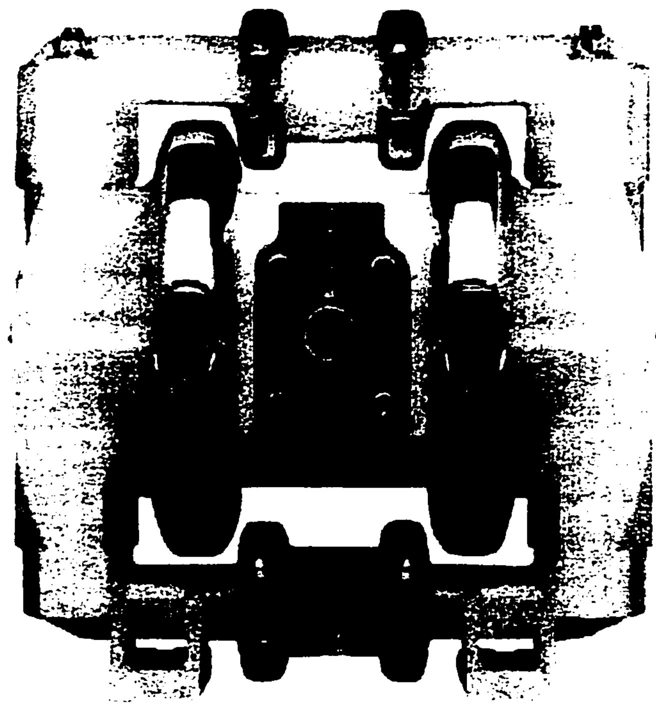


Figure 3-9 Wilden Air-Operated Pump A1

Input/Output Interface Module Design

All the sensor signals are wired to the Input/Output Module box (see Figure 3-10) that was connected to the data acquisition board by a cable. A digital output pin on the data acquisition board is used to control the stroke rate of the pump. A solid-state relay, DMO063, is used to electrically isolate the pump coil circuit and the data acquisition board. The operating current of DMO063 is 20mA. As specified in Table

3-1, the maximum digital output current is 2.5mA. Therefore, an inverter (7406N) is used to provide sufficient current sink to drive the solid-state relay. A schematic of the pump control circuitry is depicted in Figure 3-11.

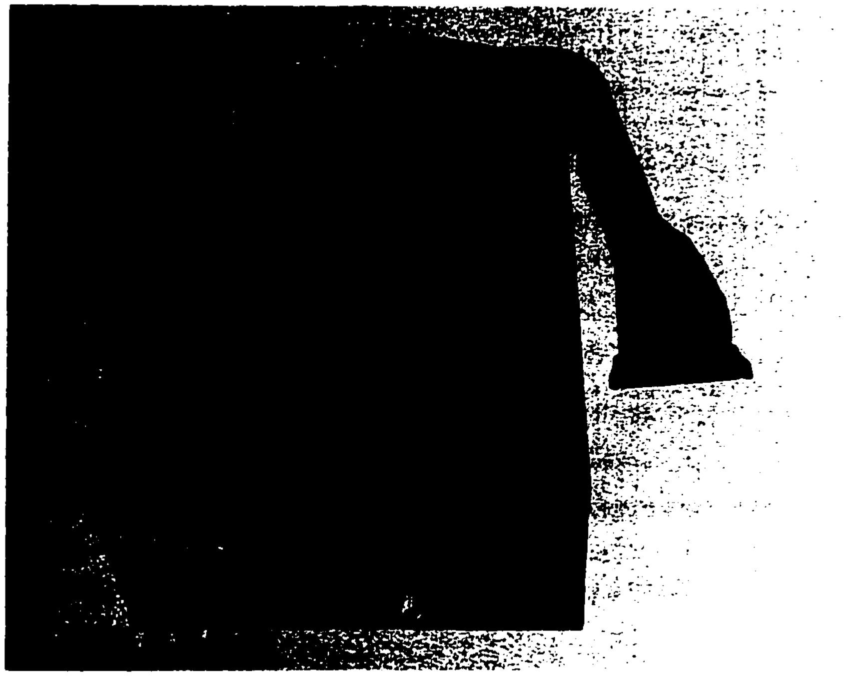


Figure 3-10 Input/Output Interface Module

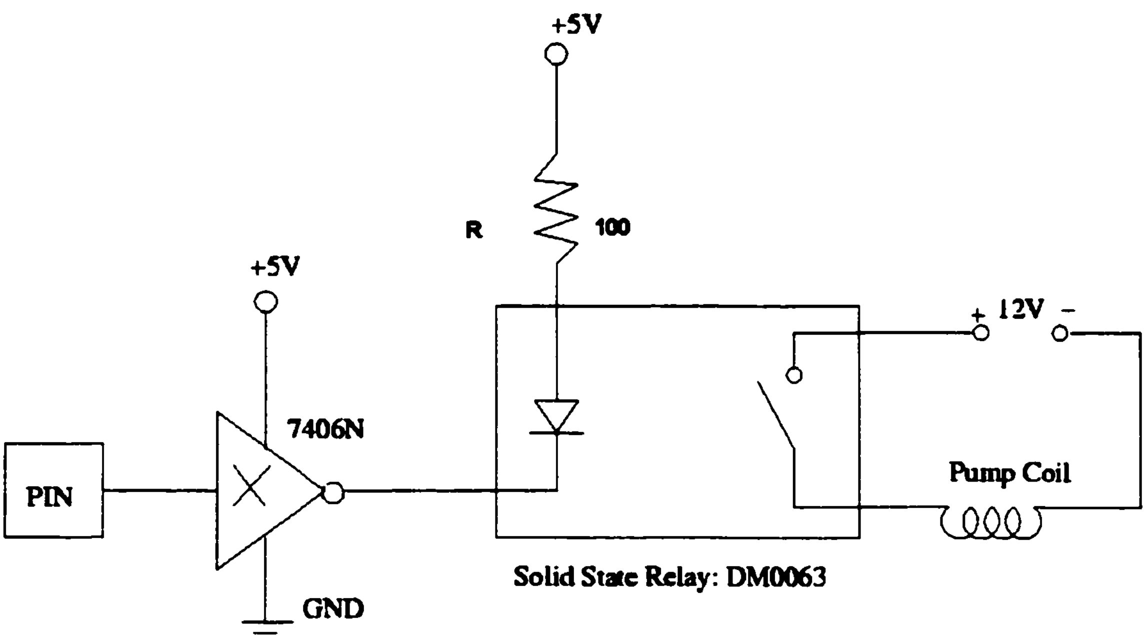


Figure 3-11 Schematic of Pump Control Circuit

3.2.3 Software Design and Implementation

The main functionality of the software program running on a PC is to acquire and monitor data, and to log it to the disk for later analysis. The software program acquires data by interfacing to the plug-in data acquisition board housed in the PC. The interface of the program is shown in Figure 3-12, which was captured during an experiment.

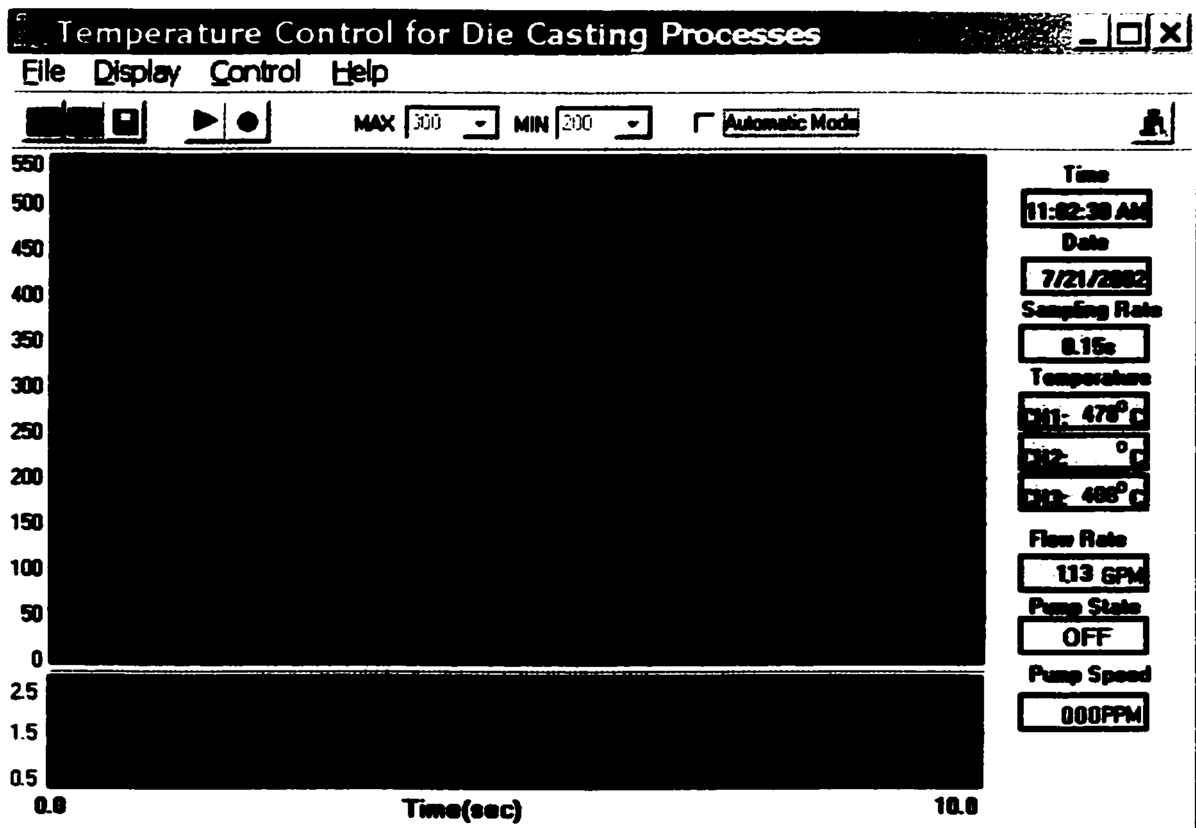


Figure 3-12 Software Graphical User Interface

The main program routine is divided into four sub-function modules: data-sampling module, data-display module, data-saving module, and pump-control module.

The data-sampling module is responsible for acquiring data by interfacing to the data acquisition board at a sampling rate that is specified by software. The data-display module displays data on the screen in the format of curve and values. The data-saving module saves data to the disk in an ASCII text file format. The pump-control module is responsible for providing control functionality such as setting the pump speed.

The data-sampling module is triggered once every sampling period. The data-display, saving, and pump-control modules can be executed by user input. The flowchart of the program routine is shown in Figure 3-13.

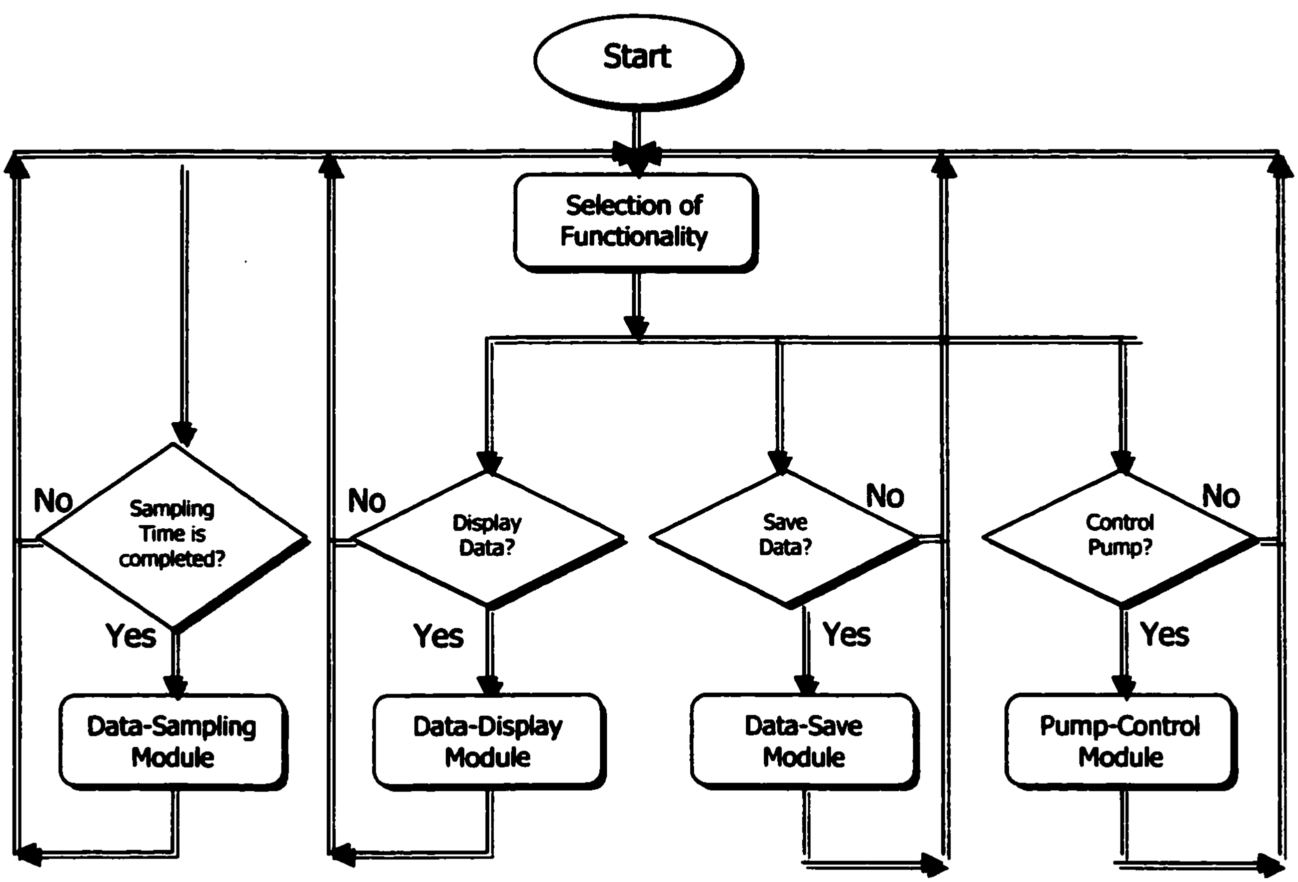


Figure 3-13 Flowchart of Main Program Routine

The pump-control module has two operation modes: manual mode and automatic mode. User instructions control which mode is active at a given time. The selection of the operation mode is available on the graphical user interface. The manual mode flowchart is shown in Figure 3-14.

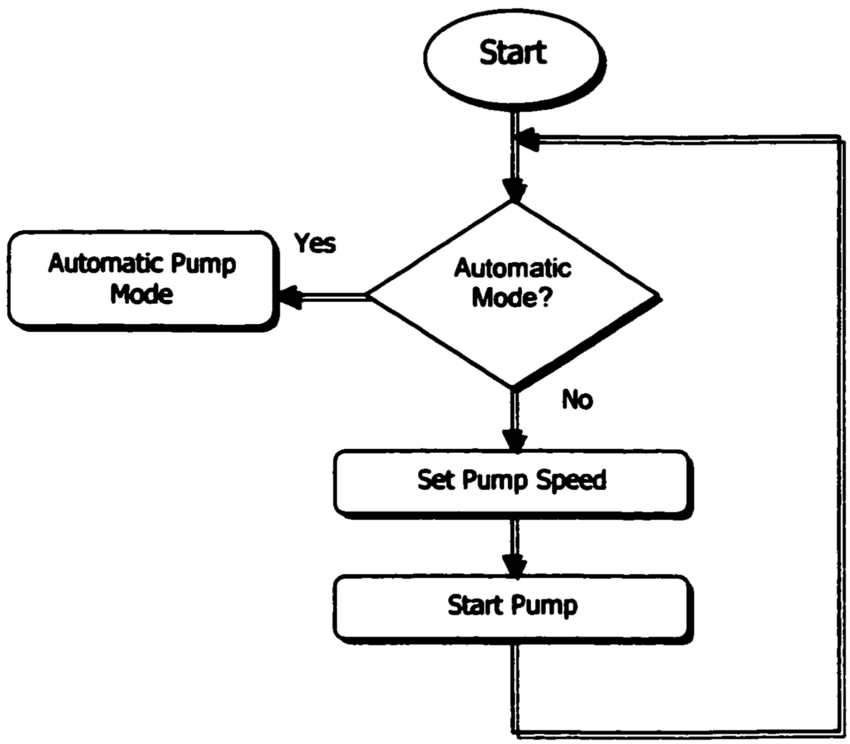


Figure 3-14 Flowchart of Pump Manual Control Mode

In the automatic mode, the pump-control module applies an ON/OFF control algorithm. The flowchart of pump automatic control mode is shown in Figure 3-15.

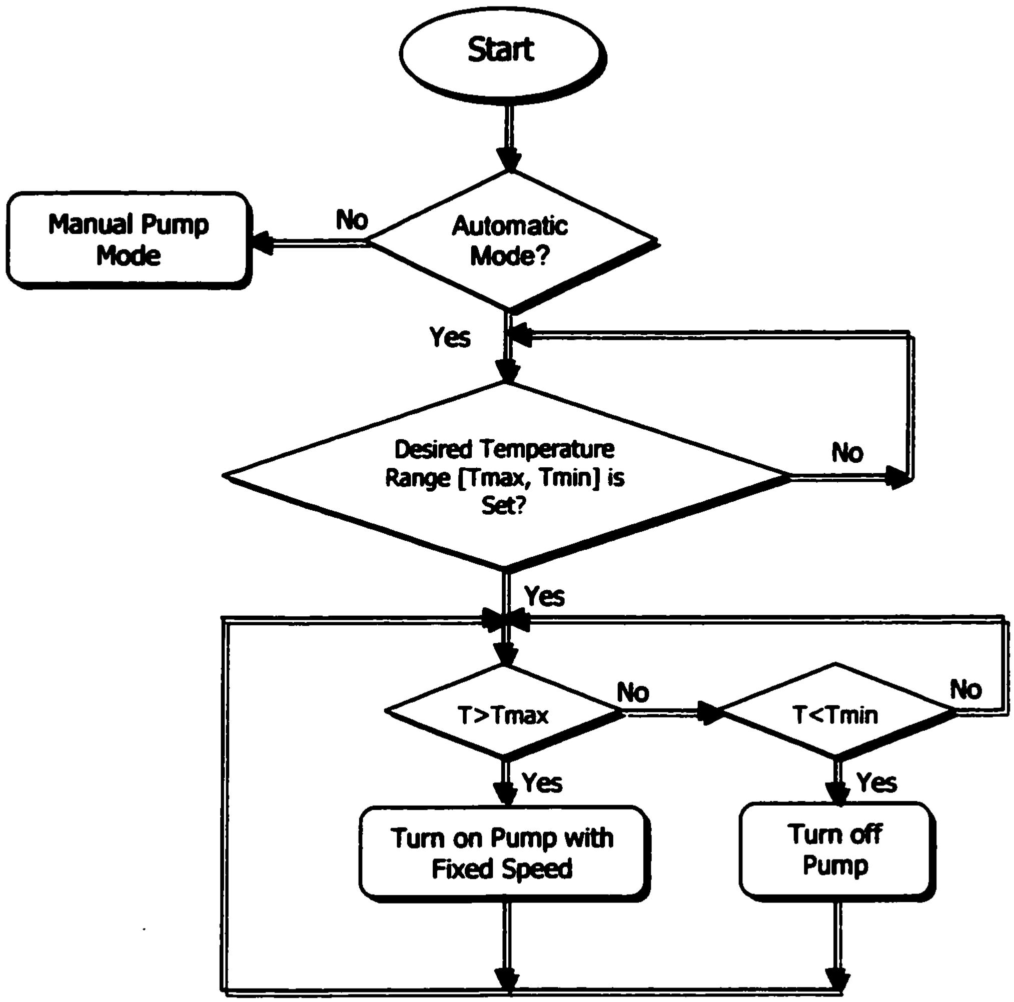


Figure 3-15 Flowchart of Pump Automatic Control Mode

3.2.4 DAS Setup

Figure 3-16 shows setup of the data acquisition system in the lab. The personal computer (PC) used for the DAS is an HP Pavilion 7850 desktop.

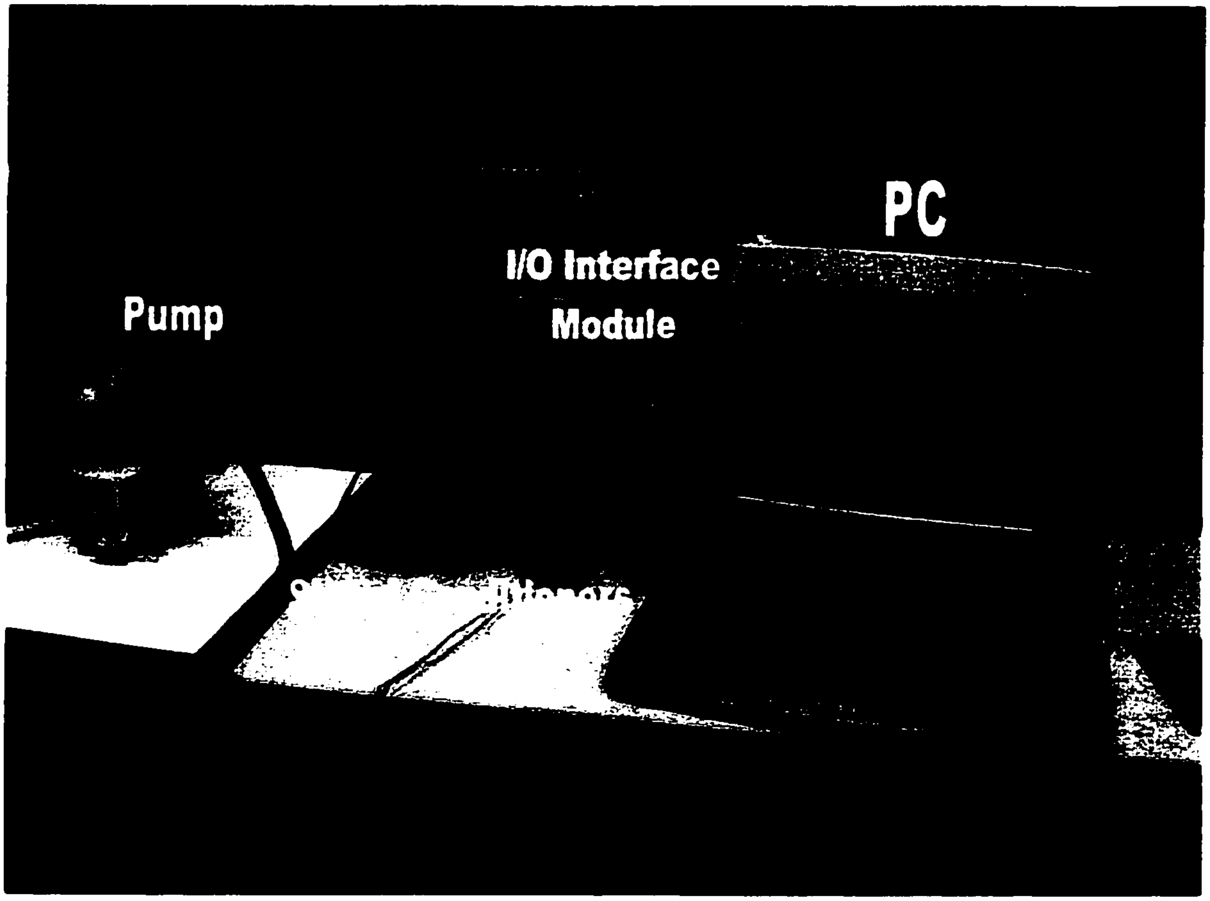


Figure 3-16 DAS Lab Setup

3.3 System Performance Evaluation

3.3.1 Accuracy

The instrument accuracy is the absolute error of the entire system including hardware and software [11]. Error has to be analyzed in order to evaluate the accuracy of the data acquisition system.

Almost all measurements are subject to two types of error: random error (noise) and systematic error. To determine the total error of the DAS, noise and systematic error have been analyzed.

Noise

Noise is unavoidable in data acquisition systems. The main sources of noise are the A/D board, signal wires, and the sensors themselves. All of these sources of noise combine to create a region of uncertainty around the signal value, thereby reducing the accuracy of the acquired data.

Random noise can be reduced by using a low noise thermocouple with a ground strap to provide protection against electrical noise. The signal conditioner has a built-in filter that can significantly reduce noise. Differential-ended inputs to the data acquisition board are adopted to reduce noise.

Because noise can be observed by repeating measurements, a simple experiment was conducted to detect the noise in the system, including noise induced by sensors, signal wires, the data acquisition board, and the PC system. Using statistical analysis, the random noise range was estimated. In the experiment, the die insert is at room temperature; neither heating nor cooling process was involved. Using the same equipment and the same procedures, temperature of the die insert was measured and recorded 10,000 times (listed at Appendix B). Figure 3-17 shows 200 readings.

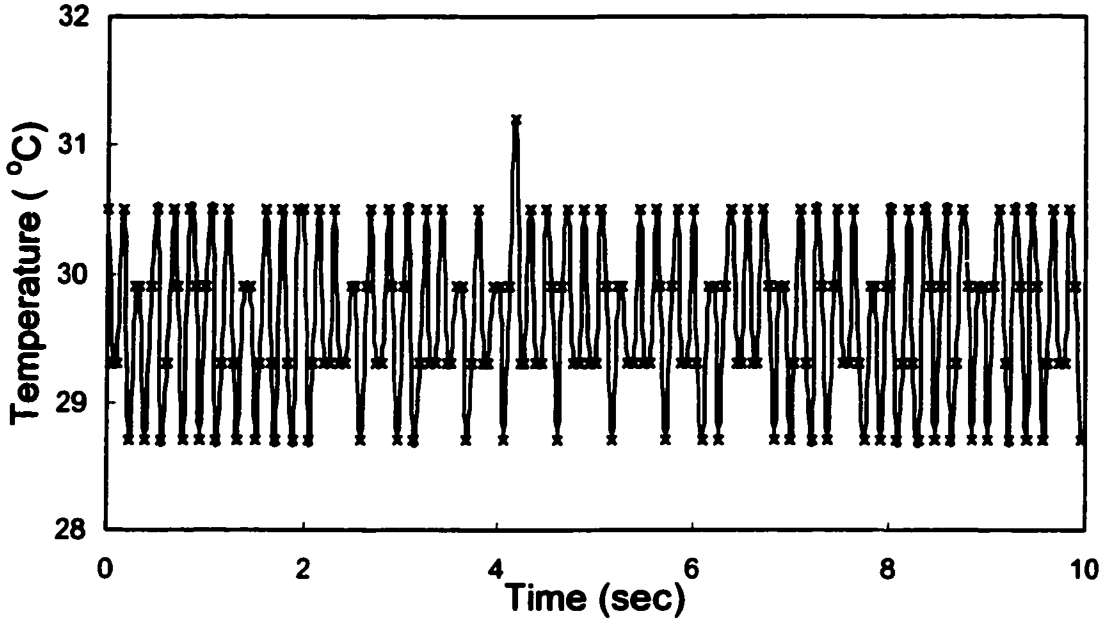


Figure 3-17 200 Readings of Die Temperature T

The mean value of these 10,000 readings $\overline{T}$ is calculated by using equation:

$$\overline{T} = \frac{1}{10000}\sum_{i=1}^{10000} T_i = 29.7\,^{\circ}\mathrm{C} \tag{3-5}$$

Standard deviation σ_T as the uncertainty in a single measurement is then calculated by:

$$\sigma_T = \sqrt{\frac{1}{10000}\sum_{1}^{10000}(T_i - \overline{T})^2} = 0.41\,^{\circ}\mathrm{C} \tag{3-6}$$

If a measurement is subject to many small sources of random error and negligible systematic error, the measurements are normally distributed that is around the true value. Therefore, there is a 70 percent probability that a signal measurement is within σ_T of the actual value.

Systematic Error

Systematic error is usually caused by an unreliable measuring device. It is nearly constant through a set of readings, and cannot be detected or reduced by statistical method. Such information is generally given in the specifications of the measuring device. Applying error propagation rules can calculate the systematic error of the entire system. For the laboratory system, the main systematic error is caused by the thermocouple. It is subject to the special limits of error, 1.1 degrees or 0.4% above 0°C. The systematic error of the system is about 1.1°C at 30°C, 1.6°C at 400°C, and 2.2°C at 550°C.

3.3.2 Resolution

The instrument resolution is the smallest input signal change, Δ, that can be detected by the entire system.

Hardware resolution

The smallest temperature change ΔT that can be detected by hardware is 0.6°C. The smallest water flow rate difference ΔF that can be detected by hardware is 0.00462L/min (0.00122GPM).

Software resolution

Sensors measure physical signals and convert them to electric signals. The data acquisition board converts the electric signals to binary representations. Software is responsible for transforming these binary representations to corresponding logical values and displaying them. This conversion determines the resolution of the software. The software resolution for the temperature signal is 0.1°C, and 0.0379 L/min (0.01GPM) for the water flow signal.

3.3.3 Throughput

Throughput of a PC-based data acquisition system is the speed with which the computer samples data. It is a combination of the hardware speed, the efficiency of the operating system, and the other application software all working together.

According to the specification of the data acquisition board, the maximum speed of the board is 330kHz. Therefore, the maximum sampling rate of the board is about $3\mu s$.

It is difficult to calculate the speed of the operating system and application software due to the fact that the operating system installed on the PC does not have real-time performance. However, the average speed of the software including the operating system can be experimentally estimated. Experiments revealed that the maximum sampling rate achievable by this computer is around 55ms, which limits the throughput of the entire system.

3.4 Summary

This chapter has provided an introduction to a PC-based data acquisition system. The design and implementation of this system, including the selection and design of hardware, and the software design, have been presented. The performance of the system has been evaluated.

Chapter 4

Experimental Design and Procedures

In order to design an efficient temperature controller for die casting processes, which is capable of adjusting cooling water flow rates to the dies, the following questions must be resolved by conducting experiments and by analyzing the experimental data:

1. How does temperature of a die change when varying cooling water flow rates are being applied to the internal cooling waterlines during the die closing stage?
2. How does the die internal heat flux change along the internal waterline when varying cooling water flow rates are being applied to the internal cooling waterline during the die closing stage?
3. How do the overall heat removal rates change when different cooling water flow rates are applied to the internal cooling waterline during the die closing stage?

4. How effectively does the pump work as an actuator to adjust water flow rates?

The data acquisition system developed in Chapter 3 was applied to all the experiments. However, since the objective of each of the above four questions is slightly different, several experimental setups and procedures were developed accordingly. Experiment A was designed to acquire necessary data for resolving questions 1 and 2. Experiment B was designed for question 3. Experiment C is prepared for the answer of question 4.

4.1 Design of Experiment A – Die Temperature

The objective of experiment A is to acquire temperature signals from three locations inside the die insert and the cooling water flow rate signal simultaneously. Analysis of the experimental data allowed an understanding of how the internal die temperature and the internal local heat flux change with variations in the water flow rate.

Three thermocouples are placed in holes drilled from the rear of the insert toward the casting insert surface at depths of 0.07m, 0.085m, and 0.105m. Figure 4-1 shows the relative position of three thermocouples. Local heat flux across locations 2 and 3 can be estimated by using Fourier's Law.

$$\dot{q}_n = -k\frac{dT}{dn} \tag{4-1}$$

where

$\dot{q}_n$ = Heat flux in a n-direction ($J/s{\cdot}m^2$)

k = Die H13 thermal conductivity ($J/s{\cdot}m{\cdot}K$)

T = Die temperature distribution along n direction (K)

n = Direction along which temperature gradient exists

The negative sign is a consequence of the fact that heat is transferred in the direction of decreasing temperature. Figure 4-2 shows the three-dimensional coordinate system used for the calculation.

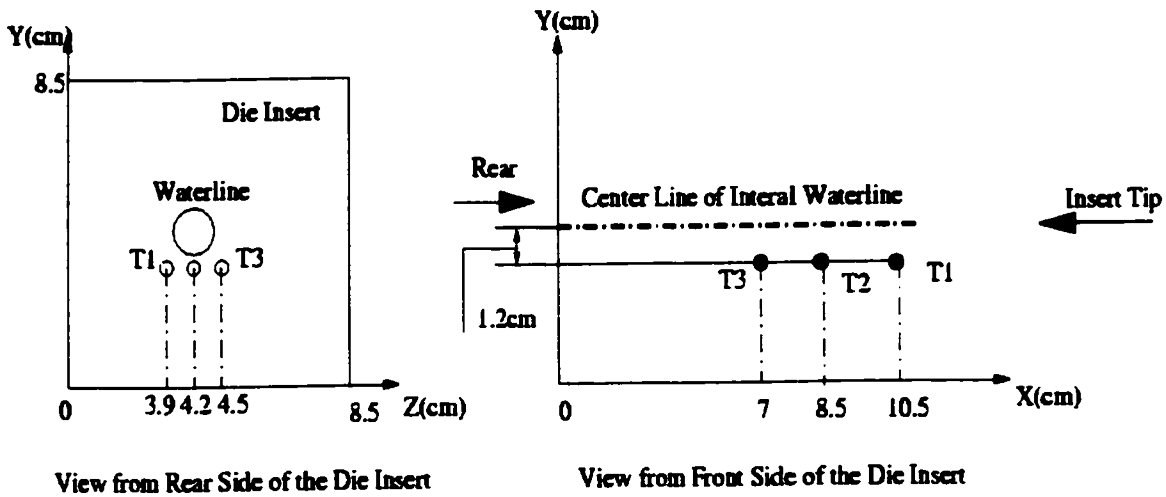


Figure 4-1 Relative Locations of Three Thermocouples

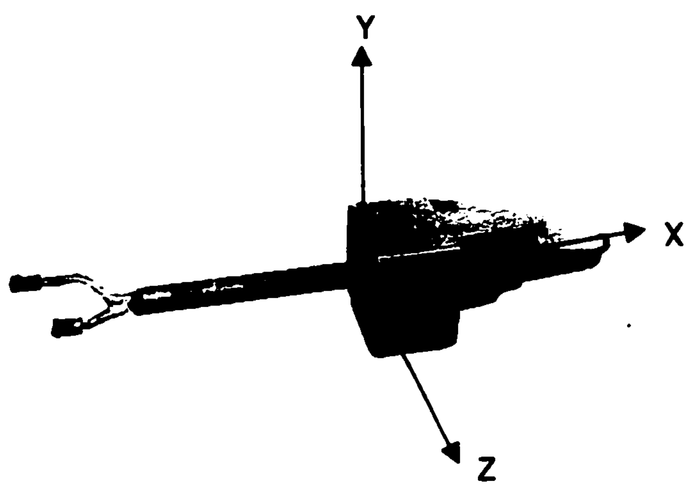


Figure 4-2 Three Dimensional Coordinate System for Calculation

Assuming a linear temperature distribution between locations 1 and 2, heat flux across location 2 can be estimated by using following equation:

$$\dot{q}_2 = -k\frac{T_1 - T_2}{L} \tag{4-2}$$

where,

$\dot{q}_2$ = Heat flux across location 2 (J/s·m^2)

T_1 = Temperature at location 1 (K)

T_2 = Temperature at location 2 (K)

L = Distance between locations 1 and 2 (m)

Assuming a linear temperature distribution between locations 2 and 3, heat flux across location 3 can be estimated by using the following expression:

$$\dot{q}_3 = -k\frac{T_2 - T_3}{L} \tag{4-3}$$

where,

$\dot{q}_3$ = Heat flux across location 2 (J/s·m^2)

T_3 = Temperature at location 3 (K)

L = Distance between locations 2 and 3 (m)

$\dot{q}_2$ and $\dot{q}_3$ can be viewed as the heat flux along the internal waterline, which is the X-direction. In an attempt to determine heat transfer from the die insert towards the waterline, heat flux in the Z-direction is also calculated using the following equations:

$$\dot{q}_{3,Z}(t) = -k\frac{T_2(t) - T_3(t)}{z_2 - z_3} = -k\frac{\Delta T_{2-3}(t)}{\Delta z} \tag{4-4}$$

where,

$\dot{q}_{3,Z}(t)$ = Heat flux across location 3 in Z-direction (J/s·m^2)

k	=	Die H13 thermal conductivity (J/s·m·K)
$T_2(t)$	=	Absolute temperature of thermocouple 2 (K)
$T_1(t)$	=	Absolute temperature of thermocouple 3 (K)
Δz	=	Distance between thermocouples 2 and 3 in Z-direction (m)

To measure water flow rates in the internal waterline of the die insert, a water flow meter was installed in the water inlet. All sensor signals are wired to the input/output module, which was connected to the data acquisition board that was plugged into the PC. Because of the limited pressure of the city water supply, a water pump is installed in the waterline inlet to increase the water flow rate. Figure 4-3 shows the schematic diagram of the setup for experiment A. Experiments were conducted following the procedures shown in Figure 4-4.

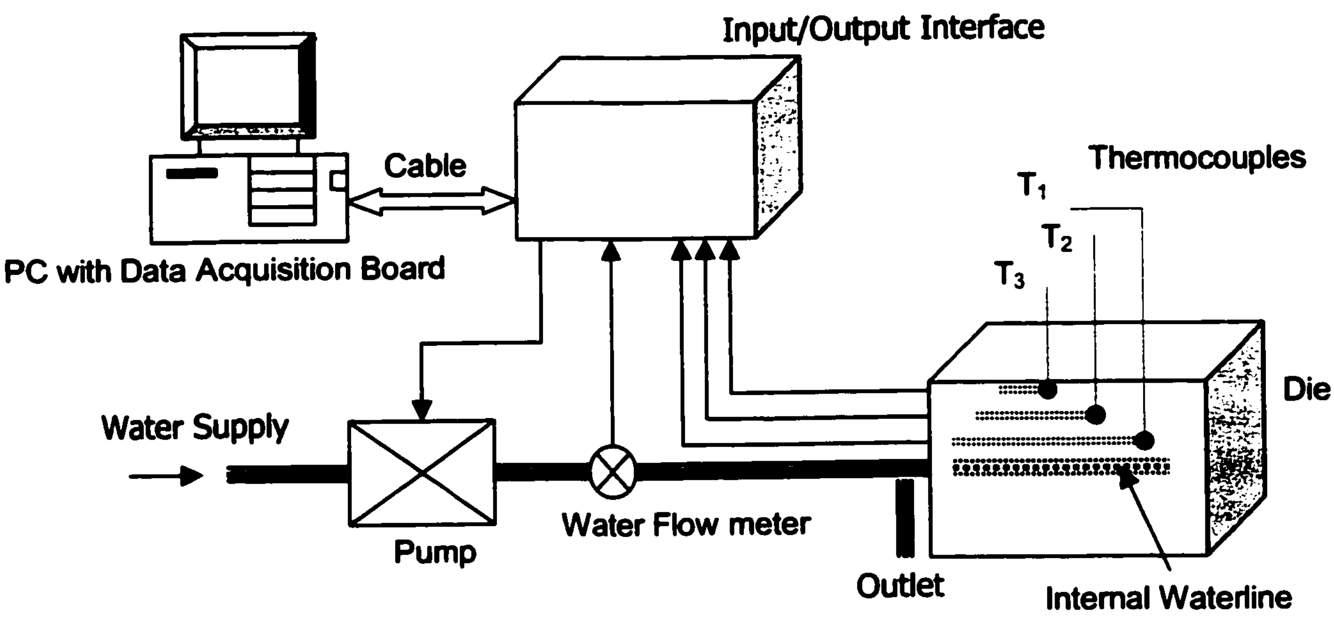


Figure 4-3 Schematic Diagram of the Setup for Experiment A

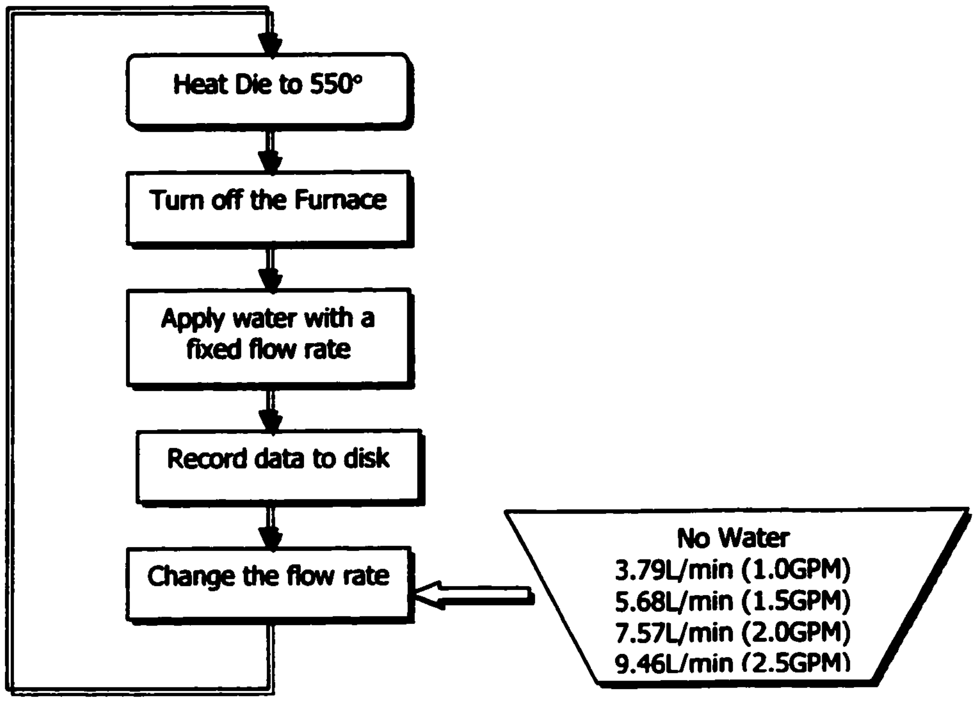


Figure 4-4 Experiment Procedures of Experiment A

4.2 Design of Experiment B – Heat Removal Rate

The objective of experiment B is to acquire the data necessary to estimate the overall heat removal rates.

The heat removal rate of the system can be estimated by using the equation:

$$q_{conv}(t) = \dot{m}c_p(T_o(t) - T_i(t)) \tag{4-5}$$

where,

$q_{conv}(t)$ = Instantaneous convection heat removal rate (J/s)

$\dot{m}$ = Cooling water flow rate (kg/s)

c_p = Specific heat of water at constant pressure (J/kg·K)

$T_o(t)$ = Outflow water temperature (K)

$T_i(t)$ = Inflow water temperature (K)

Three quantities need to be measured to calculate heat removal rates: $T_o(t)$, $T_i(t)$, and $\dot{m}$. Hence, two thermocouples are used to measure temperatures of the inlet and outlet water. A schematic diagram, which illustrates the setup of experiment B, is shown in Figure 4-5. Experiments were conducted following the same procedures shown in Figure 4-4.

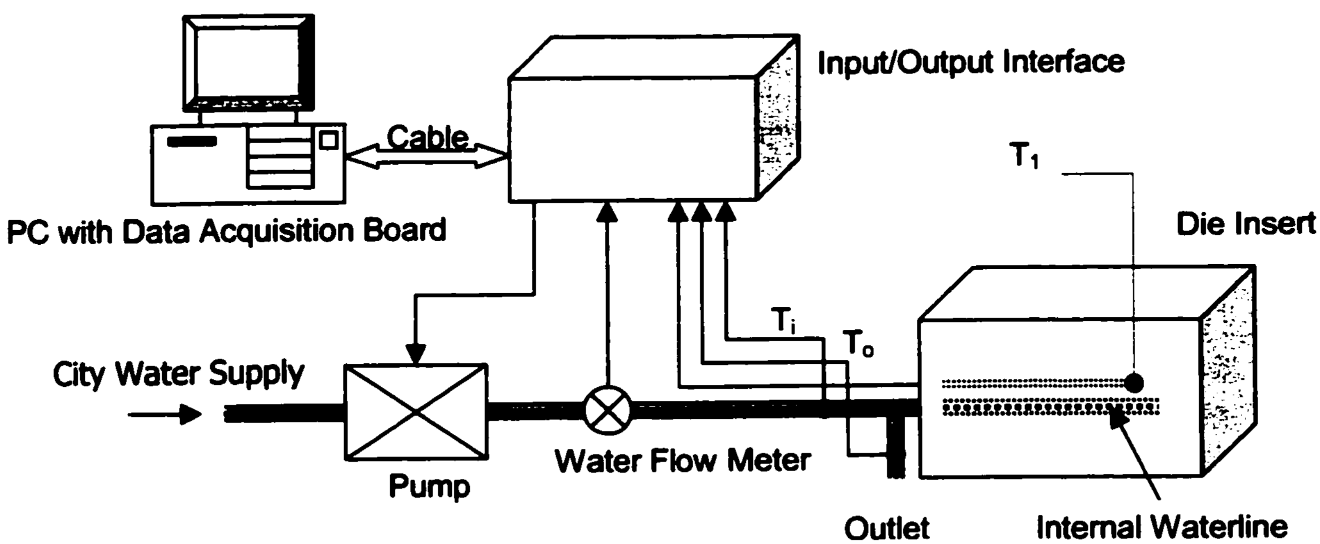


Figure 4-5 Schematic Diagram of the Setup for Experiment B

4.3 Design of Experiment C – Water Pump Control

In the experimental setup, the pump acts as an actuator and runs at certain stroke rates controlled by a computer. The water flow rate is adjusted by changing the stroke rate of the pump. During the experiments, the capability of the pump to adjust water flow rates under two types of configurations is investigated in order to generate the information necessary to design a temperature controller.

Configuration 1

In the first configuration, the pump is installed in the waterline with the city water supply. The schematic diagram of this configuration is shown in Figure 4-6.

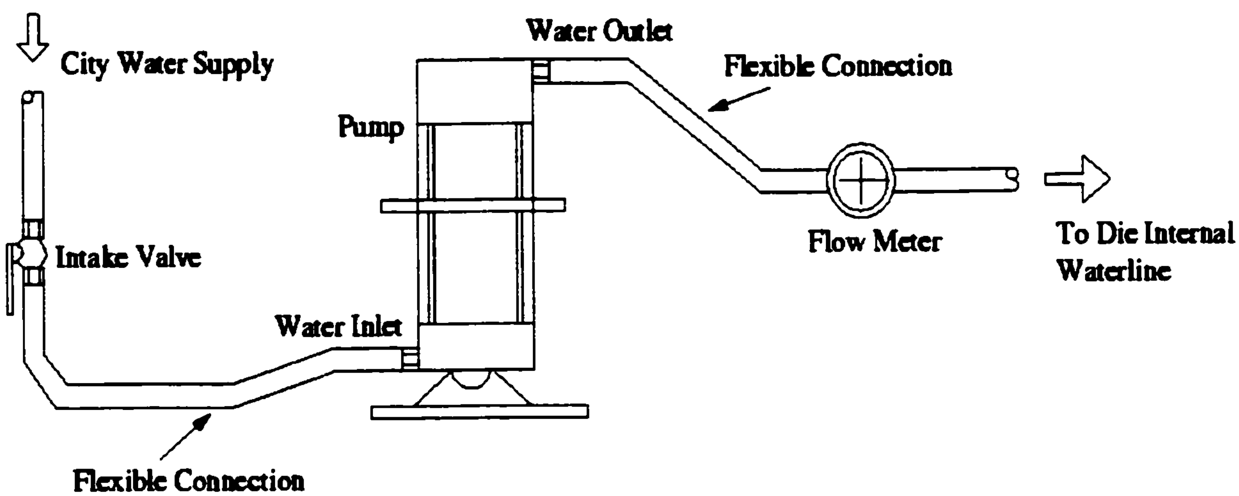


Figure 4-6 Schematic Diagram of Configuration 1 for Experiment C

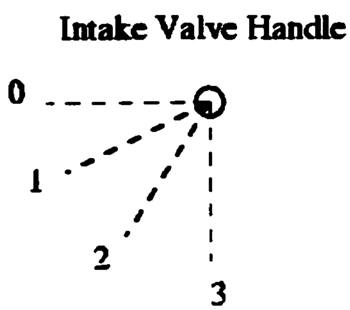
The flow rate of the system is determined by following equation:

$$F = \frac{\Delta P}{R} \tag{4-6}$$

Where,

F	= Flow rate (m^3/s)
ΔP	= Pressure difference (Pa)
R	= Resistance to flow ($kg/m^2 \cdot s$)

It is reasonable to assume that the city water pressure is fixed. When pump is off, this pressure difference is fixed. By setting the intake valve handle at different positions, the resistance to flow changes; therefore the water flow rate is adjusted. The intake valve handle position and its corresponding flow rates are shown in Figure 4-7.



0	0L/min
1	3.79L/min (1.0GPM)
2	5.68L/min (1.5GPM)
3	7.57L/min (2.0GPM)

Figure 4-7 Intake Valve Handle Positions

The pump capability of adjusting water flow rates was investigated. According to the user manual of the Wilden air-operated water pump A1, flow rates can be adjusted by changing the stroke rate of the pump. Experiments were conducted following the procedures shown in Figure 4-8. The experiments were repeated for the intake valve at positions 2 and 3, respectively.

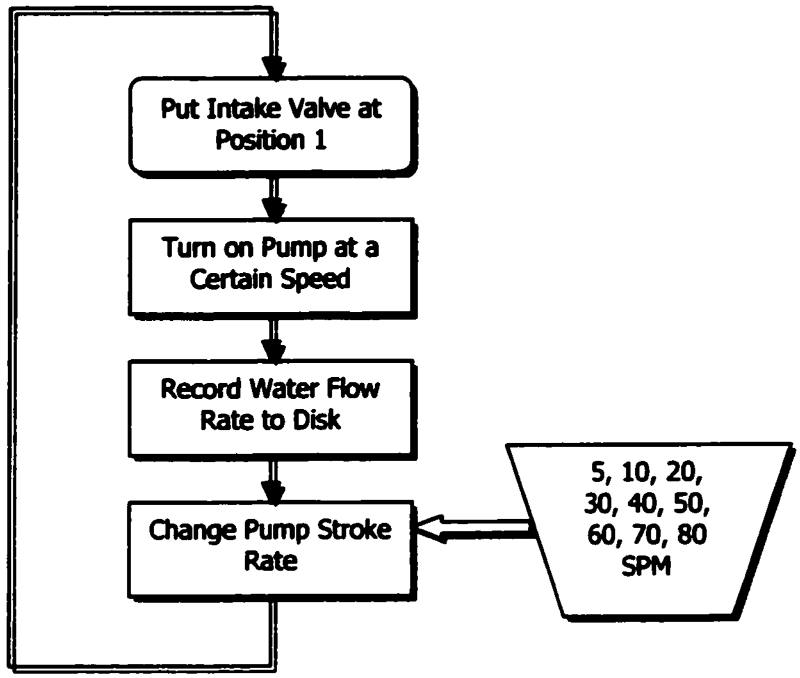


Figure 4-8 Experimental Procedures for Configuration 1

Configuration 2

Configuration 2 is set to exam the ability of the pump to adjust water flow rates when water supply is a water tank instead of city water supply. Figure 4-9 depicts this second configuration. Experiments are conducted following the procedures shown in Figure 4-10.

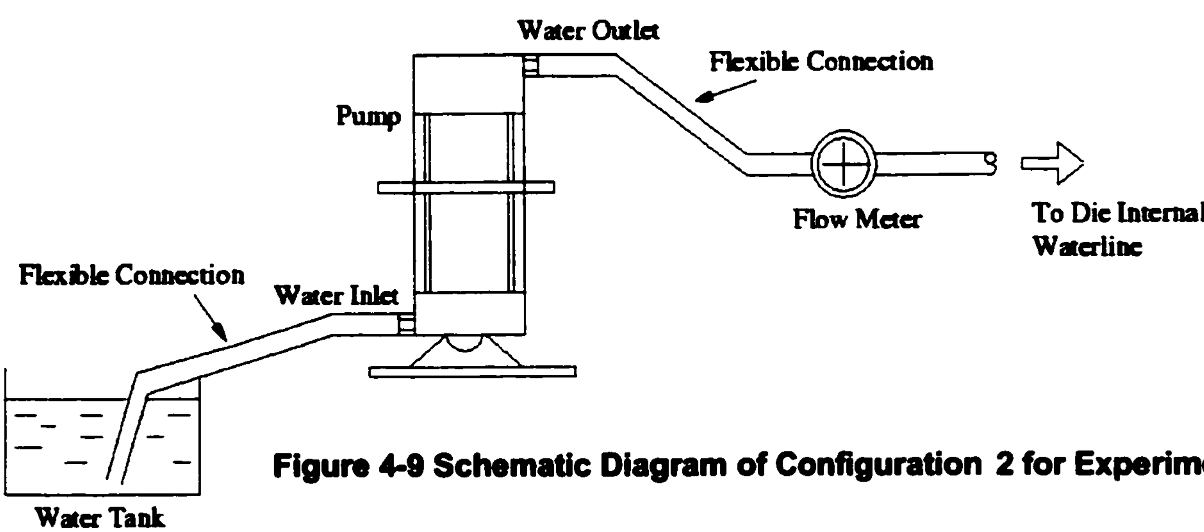


Figure 4-9 Schematic Diagram of Configuration 2 for Experiment C

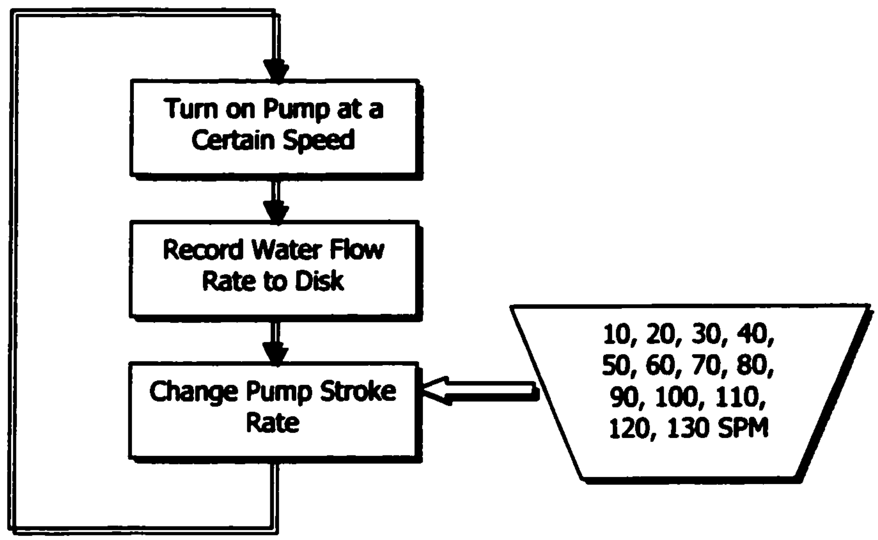


Figure 4-10 Experimental Procedures for Configuration 2

4.4 Summary

In this chapter, three experiments have been designed according to the objectives of the project. Experiment A has been designed to observe how internal die temperatures and heat fluxes change with varying water flow rates. Experiment B has been designed to acquire data necessary for estimating overall heat removal rates. Experiment C has been designed to investigate the capability of the pump as a control actuator for adjusting water flow rates. Experimental setups and procedures have been illustrated schematically.

Chapter 5

Experimental Results and Discussion

5.1 Experiment A – Die Temperature

As mentioned in Chapter 4, the objective of experiment A is to understand the effect of cooling water flow rates on die internal local temperatures and local heat fluxes. Experiments are performed and results are presented.

5.1.1 Experimental Data

Figure 5-1 shows the temperatures at three locations during the cooling time period when no water is flowing. T1, T2, T3 represent the temperatures at locations 1, 2, and 3, respectively. Figure 5-1 shows that temperatures at all locations increase. T1 increases from 530°C to 559°C, T2 from 535°C to 545°C, and T3 from 512°C to 520°C at 50 seconds after the furnace is turned off. Figures 5-2, 5-3, 5-4, and 5-5 show the variation of temperatures versus cooling time when 3.79L/min (1.0GPM), 5.68L/min (1.5GPM), 7.57L/min (2.0GPM), and 9.46L/min (2.5GPM) water flow rates are applied, respectively. According to these figures, temperatures of the die insert at Locations 1, 2, and 3 decrease rapidly after cooling water is applied. However, this decreasing slows down with increasing cooling time.

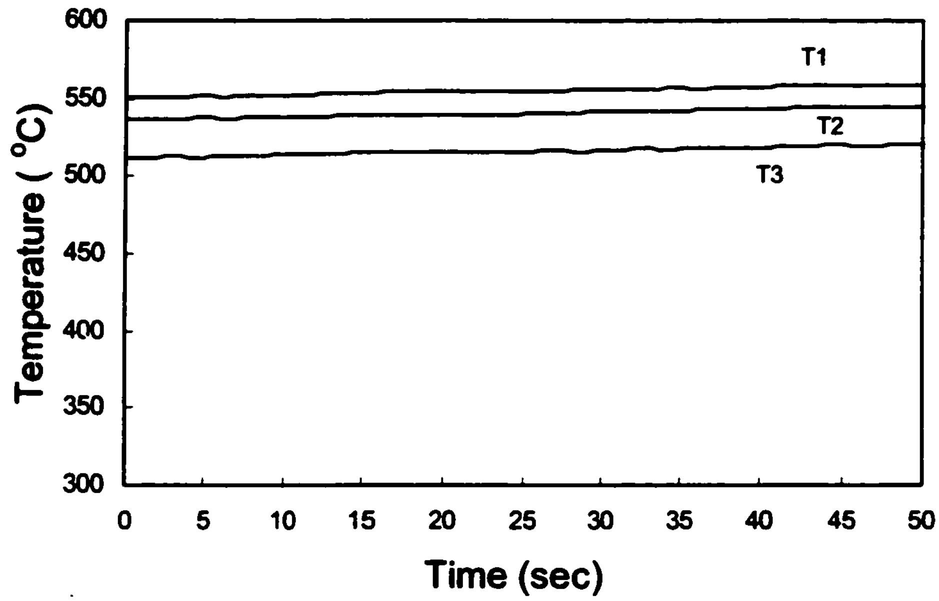


Figure 5-1 Insert Temperatures with No Water

Continuous heat transfer

In the laboratory setup, the furnace temperature is set at 800°C to heat the die insert. During the die cooling stage, even though furnace is turned off, the temperature of furnace is still higher than that of the die insert. Therefore, heat continuously transfers from the furnace to the die insert during the entire die cooling stage. The experimental results plotted in Figure 5-1 show this continued heat transfer.

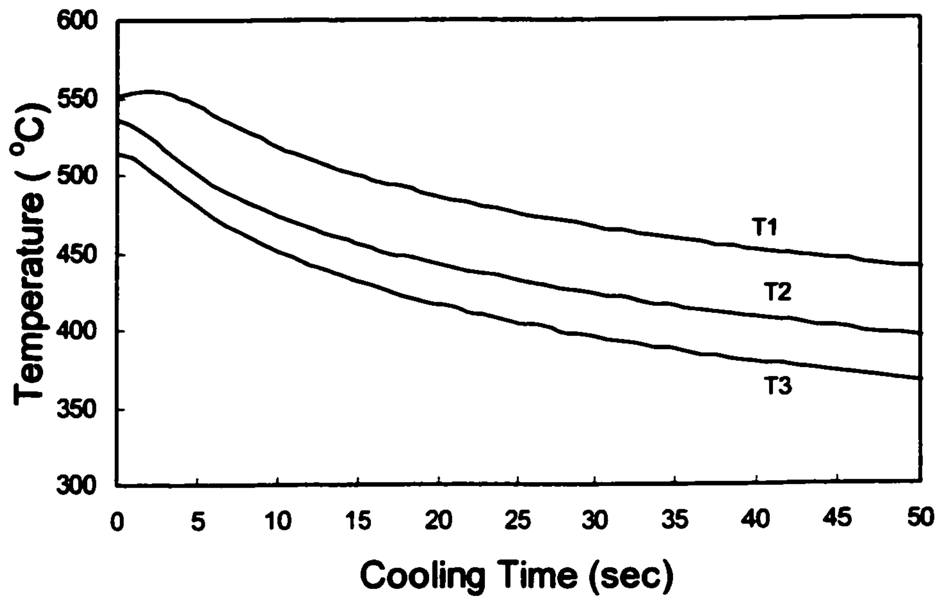


Figure 5-2 Insert Temperatures at 3.79L/min (1.0GPM)

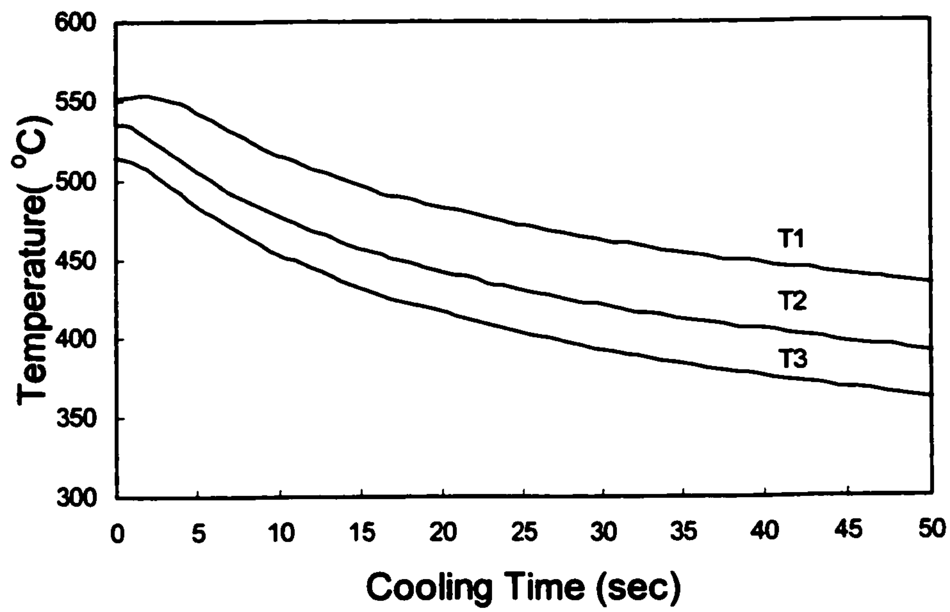


Figure 5-3 Insert Temperatures at 5.68L/min (1.5GPM)

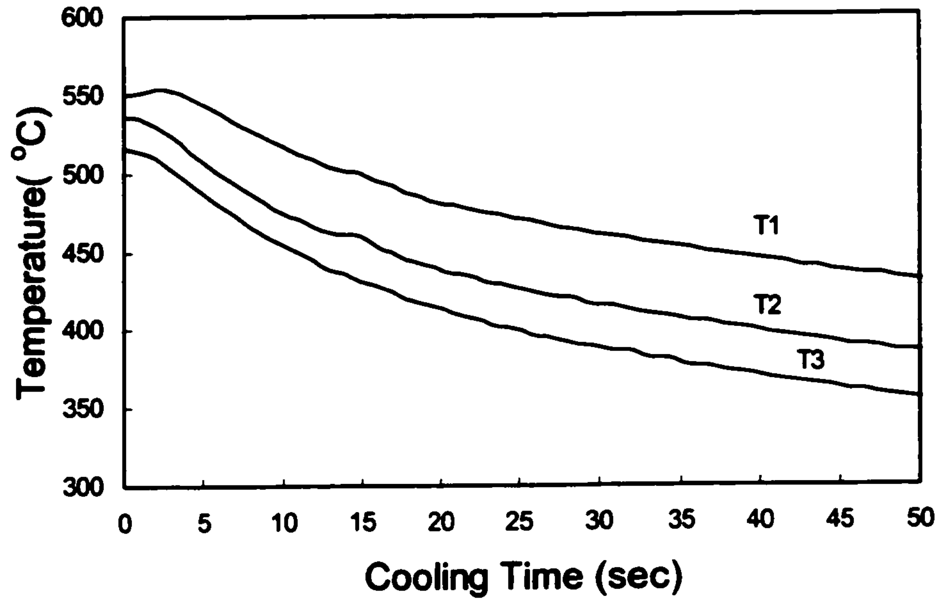


Figure 5-4 Insert Temperatures at 7.57L/min (2.0GPM)

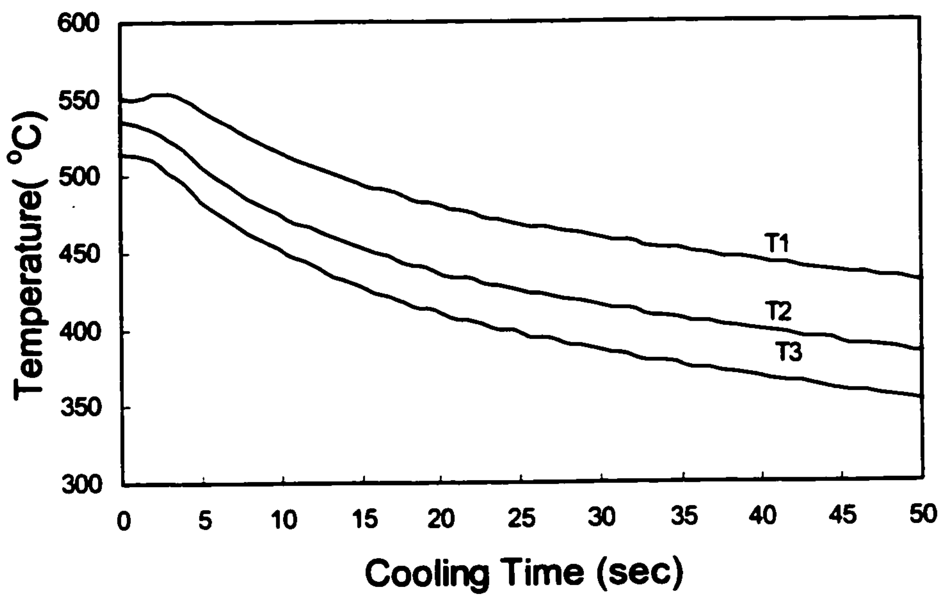


Figure 5-5 Insert Temperatures at 9.46L/min (2.5GPM)

5.1.2 Data Analysis and Observation

5.1.2.1 Effect of Flow Rates on Die Insert Temperatures

Table 5-1 shows the values of die insert temperatures at three locations with different water flow rates at a time 50 seconds after cooling starts.

Table 5-1 Effect of Flow Rates on Die Insert Temperatures

[redacted]			
3.79	439	395	366
5.68	434	391	361
7.57	430	385	355
9.46	430	384	352

According to the data in Table 5-1, the change in die insert temperature with the different flow rates is shown in Figure 5-6.

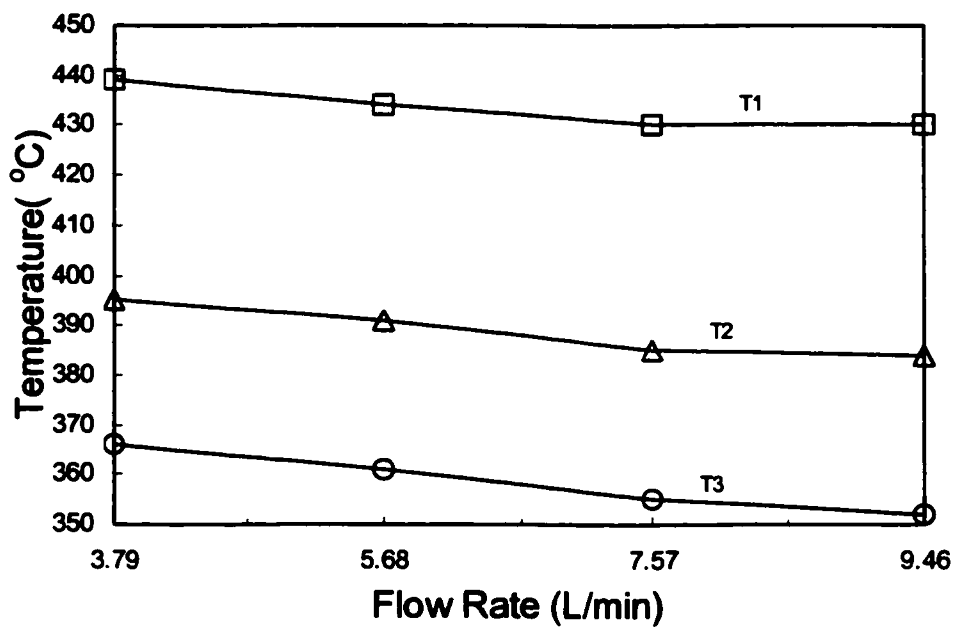


Figure 5-6 Insert Temperatures vs Water Flow Rates

When the water flow rate increases from 3.79L/min (1.0GPM) to 5.68L/min (1.5 GPM), the temperature at location 1 drops 5°C further. There is a 4°C temperature drop when flow rate changes from 5.68L/min (1.5GPM) to 7.57L/min (2.0GPM) at location 1. There is almost no temperature drop when increasing the flow rate from 7.57L/min (2.0GPM) to 9.46L/min (2.5GPM) at location 1. At location 2, the values of the temperature drop are 4°C, 4°C, and 1°C, respectively. At location 3, the values of temperature drop are 5°C, 4°C, and 3°C, respectively. Figure 5-7 shows the temperatures of the die insert at three locations when cooling water flow rates are 3.79L/min (1.0GPM), 5.68L/min (1.5 GPM), 7.57L/min (2.0GPM), and 9.46L/min (2.5GPM) at time of 50 seconds after the onset of cooling.

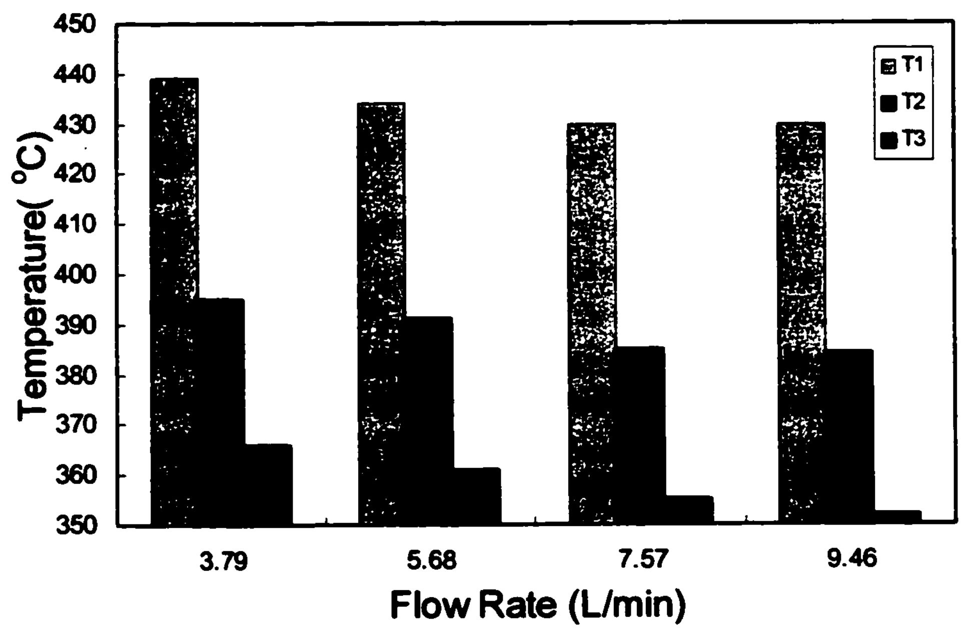


Figure 5-7 Insert Temperatures vs Water Flow Rates

Die insert temperature distribution

Due to the extremely long preheating time, the die insert internal temperature distribution in simulated experiments is more uniform than that in real die casting processes. The experimental results depicted in Figures 5-2, 5-3, 5-4, and 5-5, show that the temperature difference between T1 and T2 is about 15°C when cooling starts. However, experimental data reported by Papai et al [3] in Figure 5-8 show the temperature difference between T1 and T2 is 100°C after cavity filling stage. The distance between T1 and T2 in the Papai experiment is ten times shorter than that in the experimental setup for the current research.

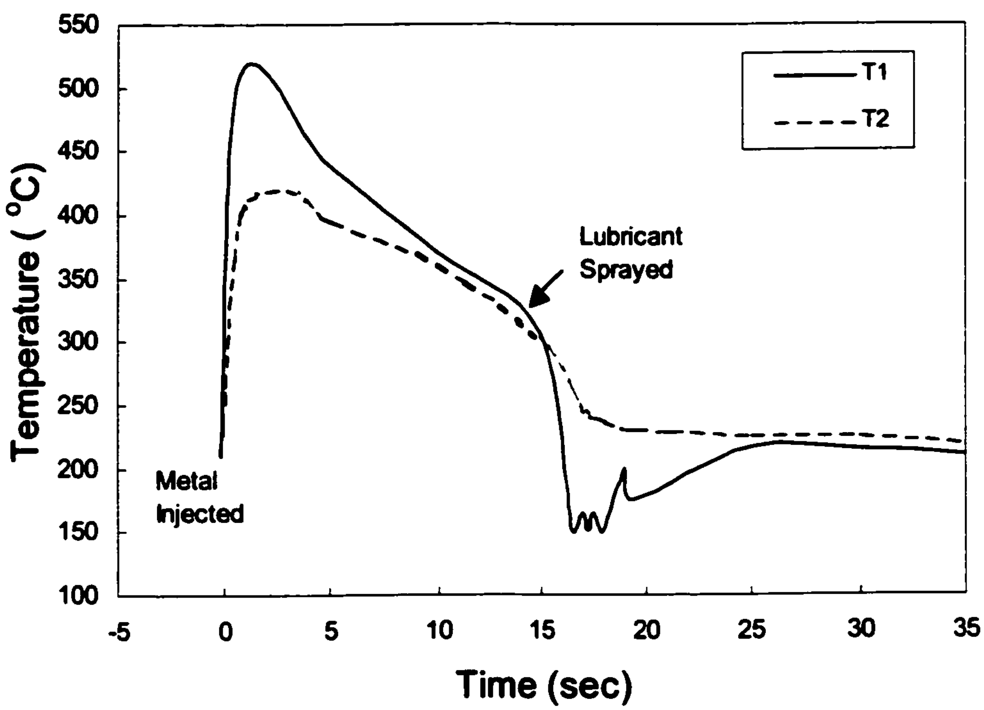


Figure 5-8 Experimental Data from Papai and Mobley [3]

Decreasing the temperature of the die insert becomes more difficult in the laboratory simulated experiments than that in real die casting processes due to the continuous heat transfer during the cooling stage and the more uniform temperature distribution. Therefore, it is reasonable to assume that in real die casting processes the temperature drop of the die insert surface will be much larger than that of the simulated experiments during the die cooling stage.

5.1.2.2 Effect of Flow Rates on Heat Flux

Temperature gradients in the die insert cause conductive heat transfer to occur in the die insert. To understand the effect of water flow rates on heat transfer away from the die insert surface, Fourier's Law is employed to compute the heat flux present in the insert:

$$\dot{q_n} = -k\frac{dT}{dn} \qquad (5\text{-}1)$$

where

$\dot{q_n}$	= Heat flux in a direction n (W/m^2)
k	= Steel H13 thermal conductivity (W/m·K)
T	= Die insert temperature distribution along n direction (K)
n	= Direction along which temperature gradient exists

The negative sign is a consequence of the fact that heat is transferred in the direction of decreasing temperature. The value of k is listed in Appendix C.

Effect of flow rates on heat flux in X-direction

The locations and distances of three thermocouples have been presented in Chapter 4. Because the distances along the X-direction are much larger than Z-direction, it is reasonable to ignore Z-direction distances between Locations 1, 2, and 3.

It is also reasonable to assume that there are local isothermal surfaces existing around locations 1, 2 and 3 at which the values of temperature are known. The temperature distribution is assumed to be linear along the direction from locations 1 to 2. Instantaneous hear flux $\dot{q_2}(t)$ across the isothermal surface 2 in the X-direction can be estimated by using the following equation:

$$\dot{q}_{2.X}(t) = -k\frac{T_1(t)-T_2(t)}{x_1-x_2} = -k\frac{\Delta T_{1-2}(t)}{\Delta x} \tag{5-2}$$

Where,

$\dot{q}_{2.X}(t)$	=	Heat flux across Location 2 at instant time t in X-direction
k	=	Steel H13 thermal conductivity (W/m·K)
$T_2(t)$	=	Absolute temperature at location 2 at instant time t
$T_1(t)$	=	Absolute temperature at location 1 at instant time t
Δx	=	Distance between location 1 and 2 in X-direction

Instantaneous heat flux $\dot{q_3}(t)$ across location 3 in X-direction can be determined by using the equation:

$$\dot{q}_{3.X}(t) = -k\frac{T_2(t)-T_3(t)}{x_2-x_3} = -k\frac{\Delta T_{2-3}(t)}{\Delta x} \tag{5-3}$$

where,

$\dot{q}_{3.X}(t)$	=	Heat flux across Location 3 at instant time t in X-direction
$T_3(t)$	=	Absolute temperature at location 3 at instant time
Δx	=	Distance between location 2 and 3 in X-direction

Figures 5-7 and 5-8 show the instantaneous heat fluxes $\dot{q}_{2,X}(t)$, and $\dot{q}_{3,X}(t)$ when the water flow rate varies.

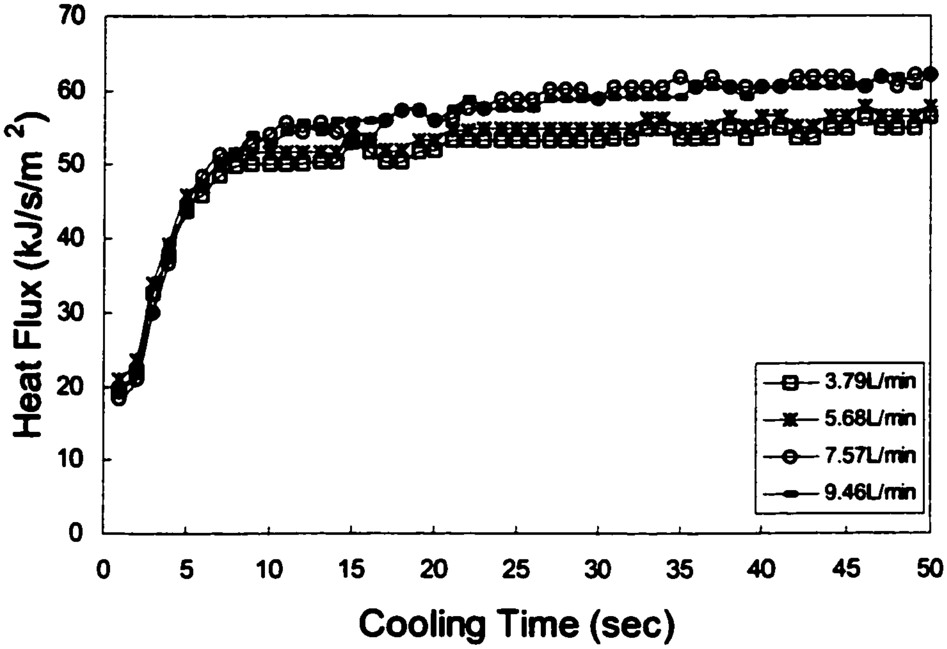


Figure 5-9 Heat Fluxes across Location 2 in X-direction

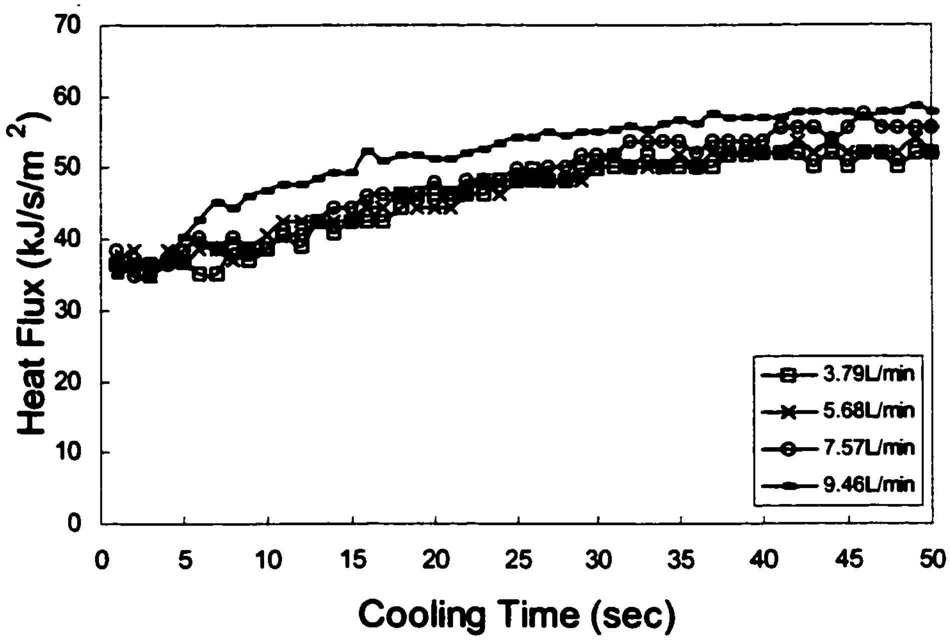


Figure 5-10 Heat Fluxes across Location 3 in X-direction

Table 5-2 shows the values of heat flux across location 2 and 3 at a time 50 seconds after the start of cooling.

Table 5-2 Effect of Flow Rates on Heat Flux in X-direction

[illegible]	[illegible]	[illegible]
3.79	59.47	52.27
5.68	59.50	52.29
7.57	63.58	55.91
9.46	64.93	59.52

Observations

From the experimental results, after cooling water is applied, the heat flux $\dot{q}_{2,X}(t)$ increases in the first 10 seconds and then stays nearly constant. While heat flux $\dot{q}_{3,X}(t)$ gradually increases, increasing the water flow rate increases the heat flux along the cooling waterline (X-direction). However, this increase does not seem significant because it is within the limits of measurement error.

Effect of flow rates on heat flux in Z-direction

Experiments are conducted to examine the heat flux across Location 3 in the Z-direction. Thermocouple 2 is moved back so that it is located at the same depth as thermocouple 3. Experiments have been conducted following the same procedures as the previous experiments. Figure 5-11 shows the temperatures of T3 and T2 when 3.79L/min (1GPM) water flow rates are applied during the cooling stage. Figure 5-12 shows T3 and T2 when 7.57L/min (2GPM) water flow rates are applied.

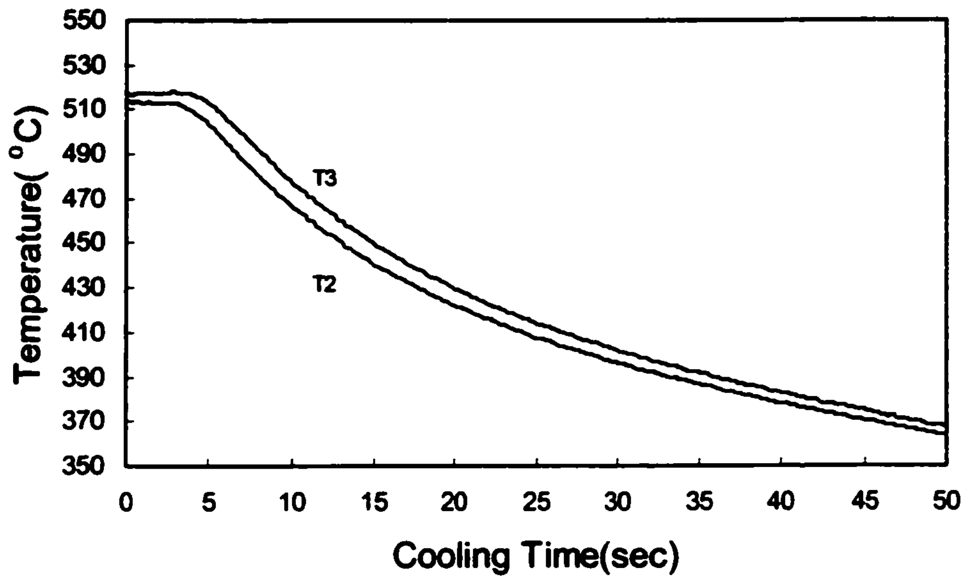


Figure 5-11 Insert Temperatures at 3.79L/min (1GPM)

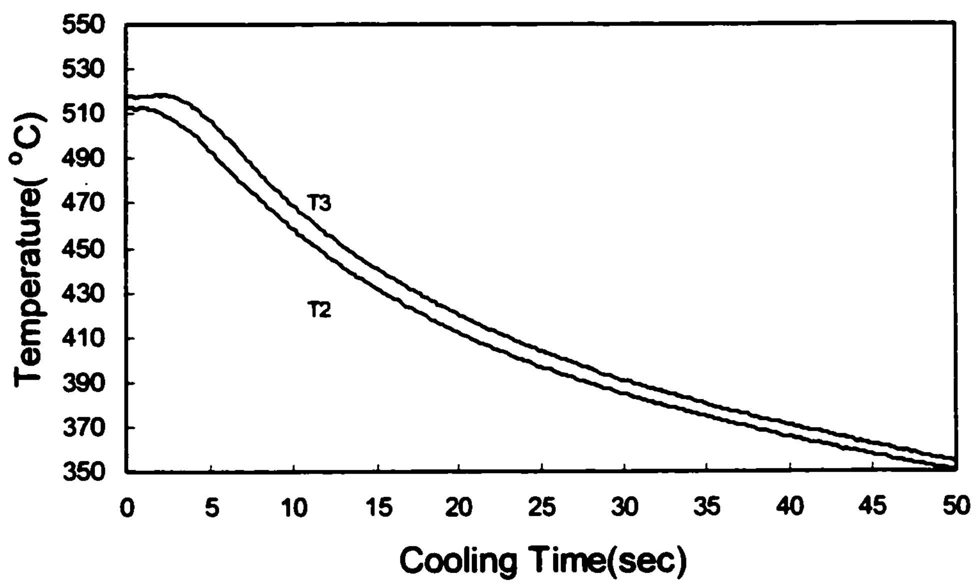


Figure 5-12 Die Insert Temperatures at 7.57L/min (2GPM)

The temperature difference between T3 and T2 is caused by the distance in the Z-direction between Thermocouple 3 and Thermocouple 2. Heat Flux across Location 3 in the Z-direction is then estimated by equation:

$$\dot{q}_{3,Z}(t) = -k\frac{T_2(t)-T_3(t)}{z_2 - z_3} = -k\frac{\Delta T_{2-3}(t)}{\Delta z} \quad (5\text{-}4)$$

where,

$\dot{q}_{3,Z}(t)$	=	Heat flux across Location 3 in Z-direction (J/s·m^2)
k	=	Die H13 thermal conductivity (W/m·K)
$T_2(t)$	=	Absolute temperature of Thermocouple 2 (K)
$T_1(t)$	=	Absolute temperature of Thermocouple 3 (K)
Δz	=	Distance between Thermocouples 2 and 3 in Z-direction (m)

Figure 5-13 depicts the heat fluxes across Location 3 in the Z-direction when 3.79L/min (1GPM) and 7.57L/min (2GPM) water flow rates are applied to the internal cooling line.

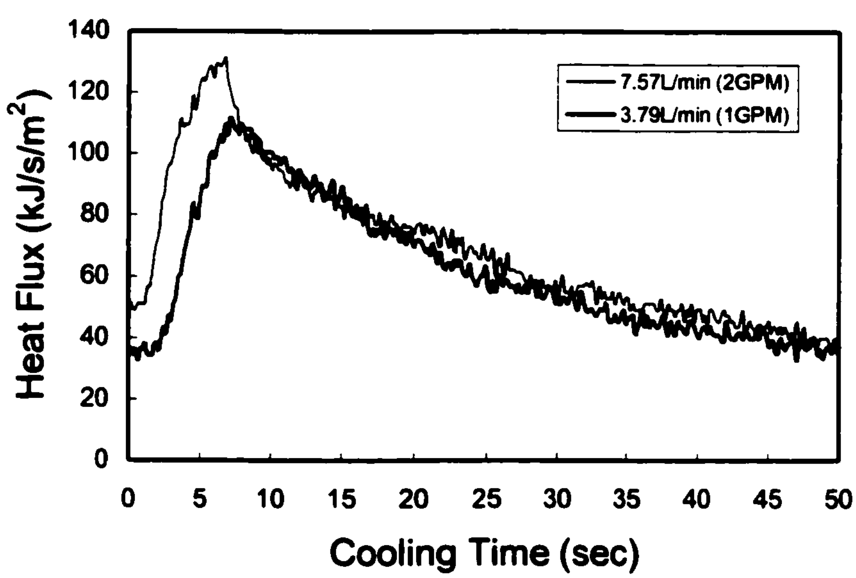


Figure 5-13 Heat Fluxes across Location 3 in Z-direction

Table 5-3 Effect of Flow Rates on Heat Flux in Z-direction

[redacted]	1	5	10	15	20
	36.31	84.72	100.55	89.38	69.83
	51.21	122.9	98.69	82.86	76.34

Observations

Heat flux in the Z-direction is a function of time; it increases rapidly and reaches a maximum value in less than 10 seconds and then decreases gradually. The heat flux in the Z-direction is also a function of cooling water flow rates. Experimental results show that a larger water flow rate causes much larger heat flux in Z-direction during the first 10 seconds of cooling. The time for heat flux to reach its maximum value decreases with higher water flow rates.

5.2 Experiment B – Heat Removal Rate

The objective of the experiment B is to acquire the data necessary for estimating overall heat removal rates when varying water flow rates are applied.

5.2.1 Experimental Data

Figures 5-14, 5-15, 5-16, and 5-17 depict the temperatures of the water inlet and outlet when 3.79L/min (1.0GPM), 5.68L/min (1.5GPM), 7.57L/min (2.0GPM), and 9.46L/min (2.5GPM) flow rates are applied.

The experimental data show that the temperatures at the inlet flow are approximately the same during the experiments. After cooling water is applied, the outlet flow temperatures drop rapidly and then gradually reach steady values.

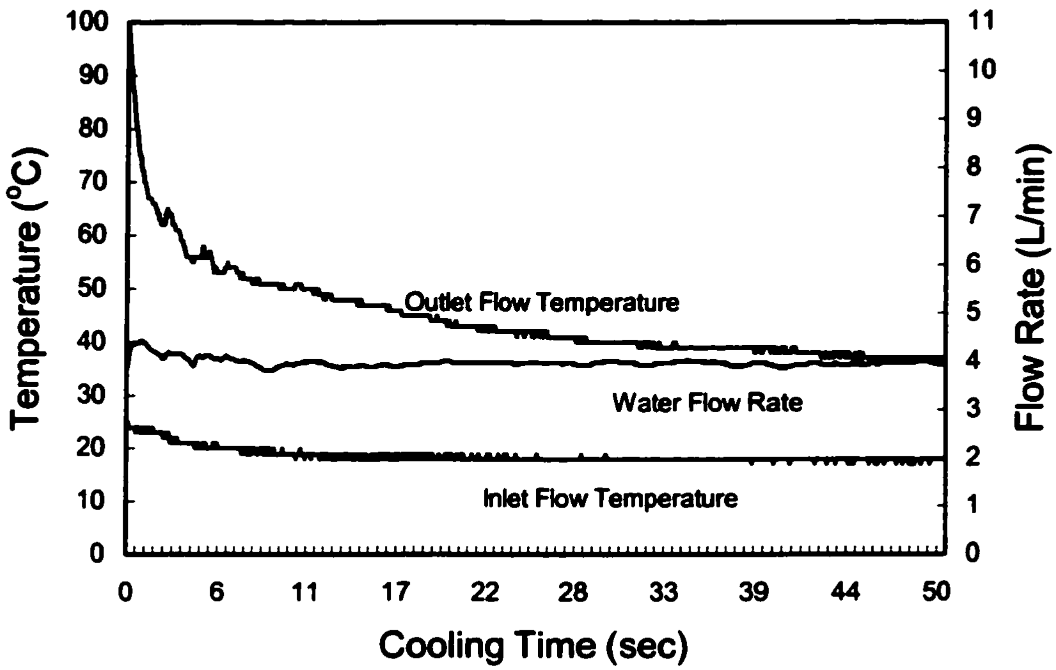


Figure 5-14 Inlet and Outlet Water Temperatures at 3.79L/min

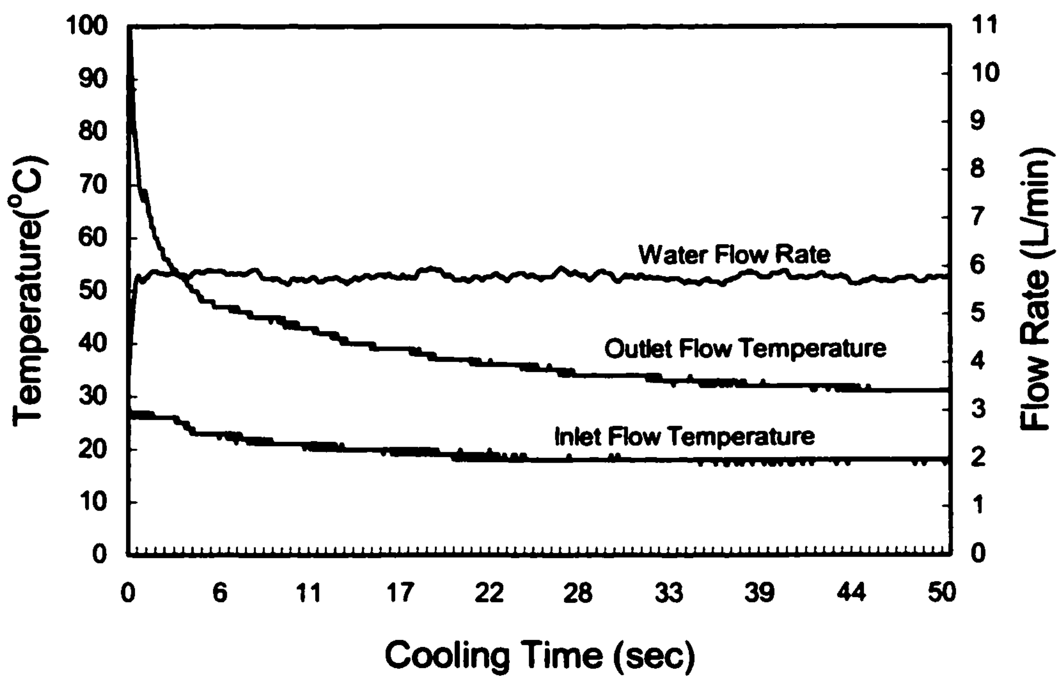


Figure 5-15 Inlet and Outlet Water Temperatures at 5.68L/min

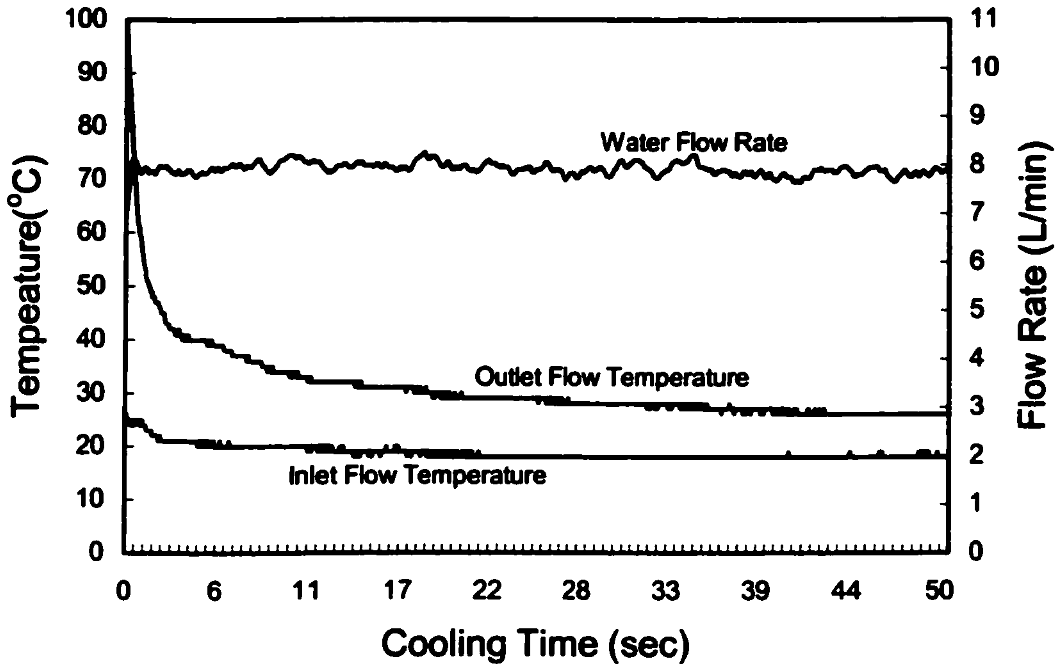


Figure 5-16 Inlet and Outlet Water Temperatures at 7.57L/min

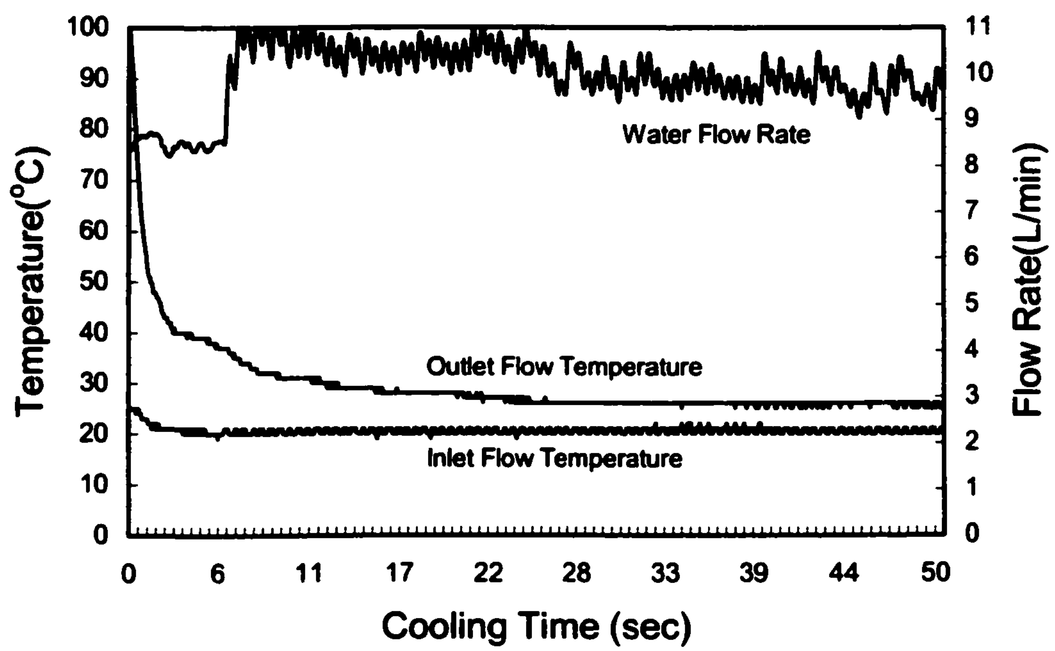


Figure 5-17 Inlet and Outlet Water Temperatures at 9.46L/min

5.2.2 Data Analysis and Observation

Transient thermal response of outlet water

The experimental data show that the time for outlet water to reach a steady state temperature becomes shorter as the water flow rate increases. It also shows that the steady state temperature of the outlet water decreases the water flow rate increases. Figure 5-18 depicts the thermal response of the cooling water at different water flow rates.

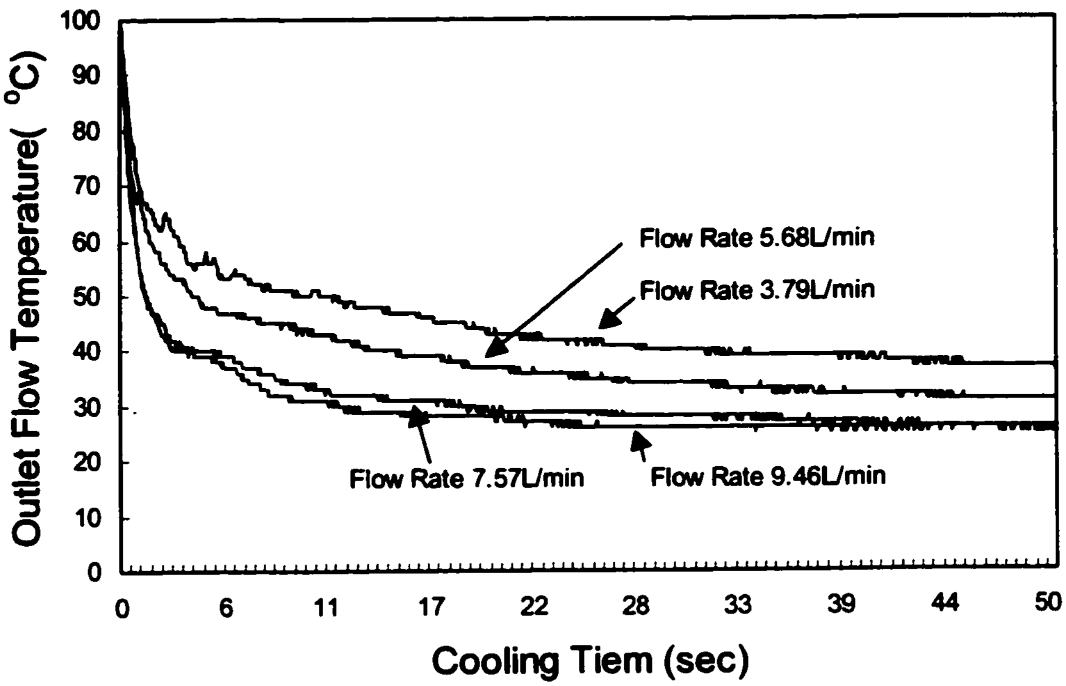


Figure 5-18 Effect of Flow Rates on Outlet Flow Temperature

Calculation of instantaneous heat removal rate

The instantaneous heat removal rate of the system can be estimated by using the equation:

$$q_{conv}(t) = \dot{m}c_p(T_o(t) - T_i(t)) \tag{5-5}$$

where,

$q_{conv}(t)$	= Entire tube heat removal rate (J/s)
$\dot{m}$	= Cooling water mass flow rate (kg/s)
c_p	= Specific heat of pure water (J/kg·K)
$T_o(t)$	= Outlet water temperature (K)
$T_i(t)$	= Inlet water temperature (K)

The specific heat of pure water is approximately 4.18 kJ/kg·K [14], and the density of water is about 1000kg/m^3 [14]. The following table converts water flow rate by volume (gallons/min) to flow rate by mass (kg/sec).

Table 5-4 Unit Conversion from Volume to Mass

[redacted]	1.0	1.5	2.0	2.5
[redacted]	0.0631	0.0946	0.126	0.158

The instantaneous heat removal rates with different water flow rates are shown in Figure 5-19. Figure 5-20 enlarges Figure 5-19 over the time period from 0 to 3 seconds. Figure 5-21 enlarges Figure 5-19 over the time period from 7 to 15 seconds.

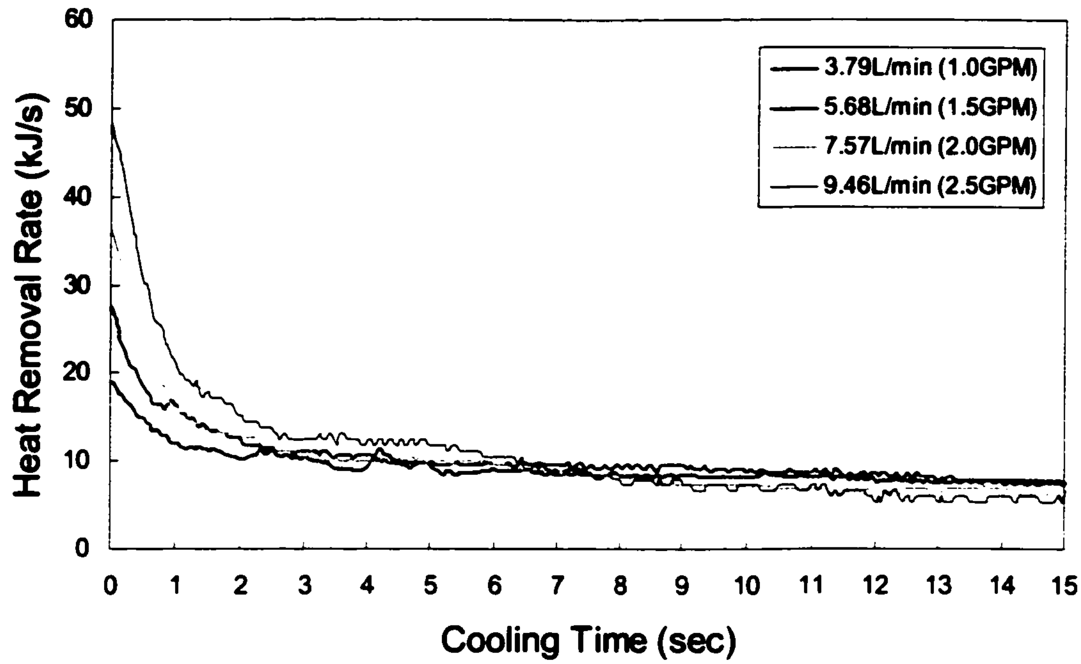


Figure 5-19 Heat Removal Rates with Varying Flow Rates

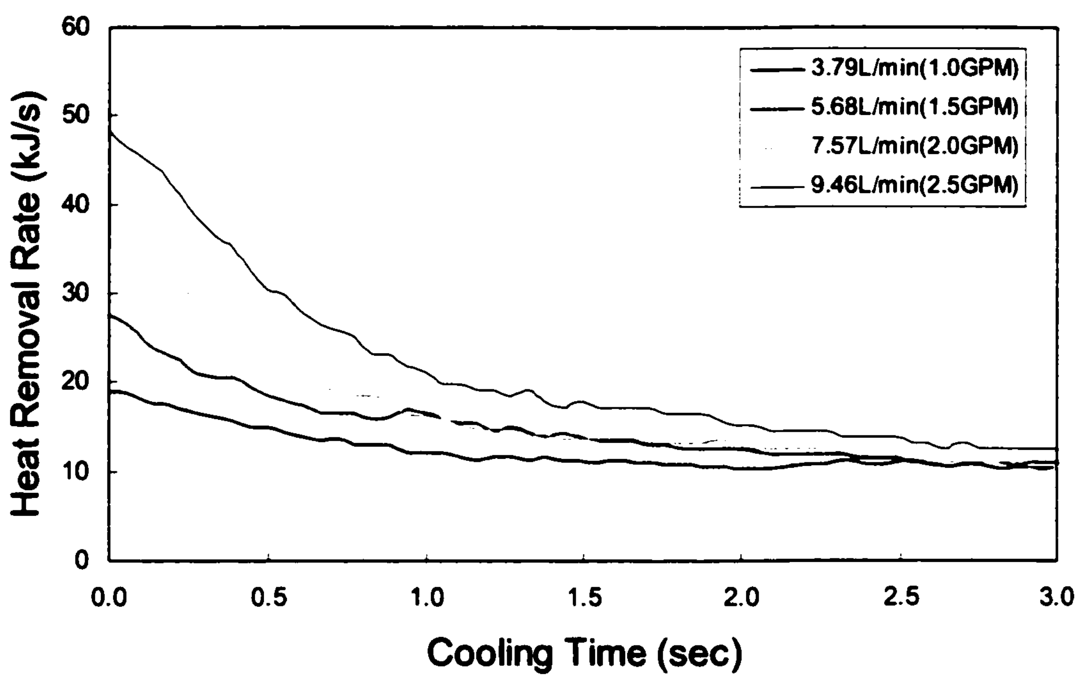


Figure 5-20 Heat Removal Rates within Cooling Time 3 seconds

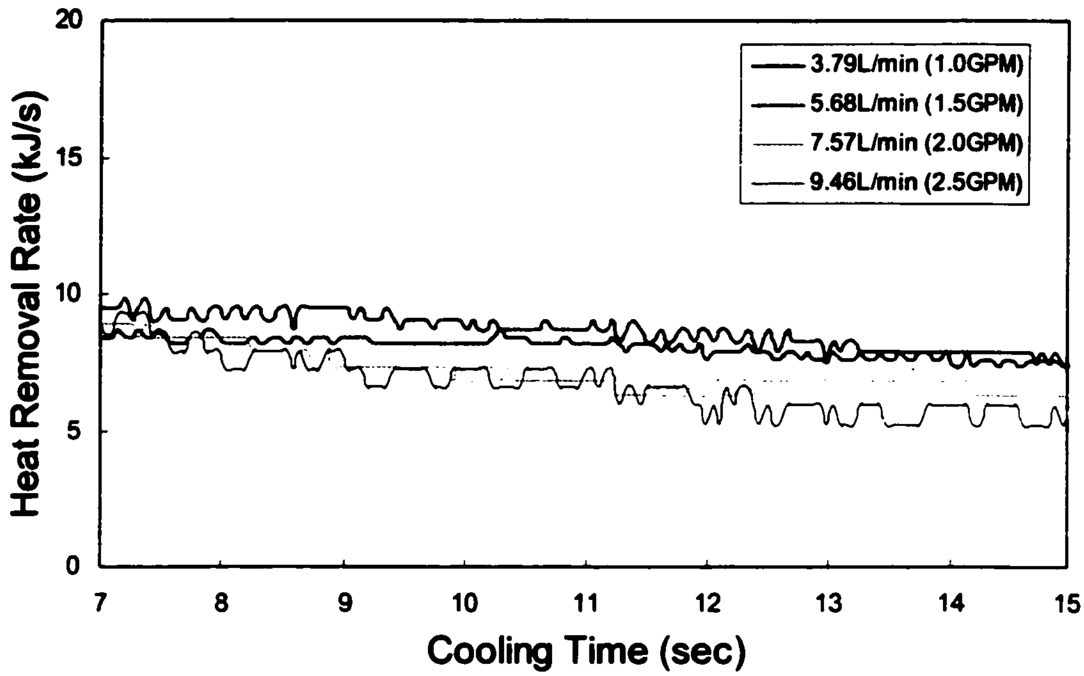


Figure 5-21 Heat Removal Rates within Cooling Time from 7 to 15 seconds

Observations

It is shown in Figure 5-19 that the total internal waterline heat removal rate is a function of cooling time. It decreases rapidly during the first 3 seconds, then, gradually decreases with further cooling time. Heat removal rate is also a function of cooling water flow rate. It is worth noting that in first 3 seconds of cooling, heat removal rates are significantly higher when the applied water flow rates are higher. However, the significance of this fact decreases with cooling time. It is also observed that after 9.49L/min (2.5GPM) has been applied for 7 seconds, the instantaneous heat removal rate of the system becomes lower than that of 3.79L/min (1.0GPM) and 5.68L/min (1.5GPM). Additional theoretical analysis is required in order to explain this phenomenon.

5.3 Experiment C – Water Pump Control

The objective of the Experiment C is to investigate the capability of the pump as an actuator to adjust water flow rates automatically. There are two configuration setups in the laboratory. In configuration 1, the pump uses the city water supply and the intake valve is used to manually change the water supply flow rates. In configuration 2, the pump uses a water tank for its water supply.

5.3.1 Experimental Data with Configuration 1

Figures 5-22, 5-23, and 5-24 show the experimental data with the pump running at a speed of 80SPM when the intake value handle is at positions 1, 2, and 3, respectively.

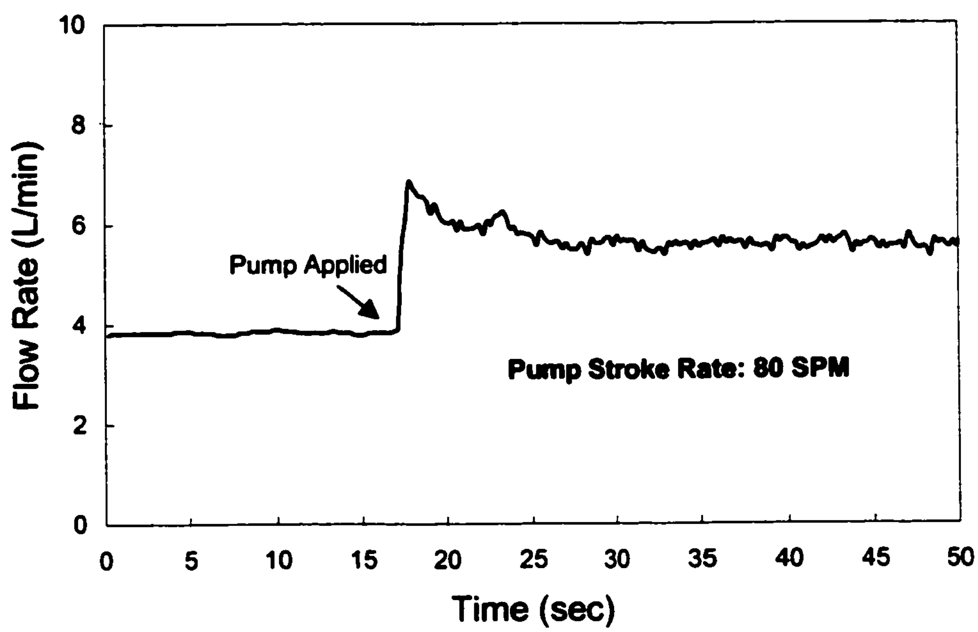


Figure 5-22 Flow Rate Adjusted by Pump at Speed 80SPM (Position 1)

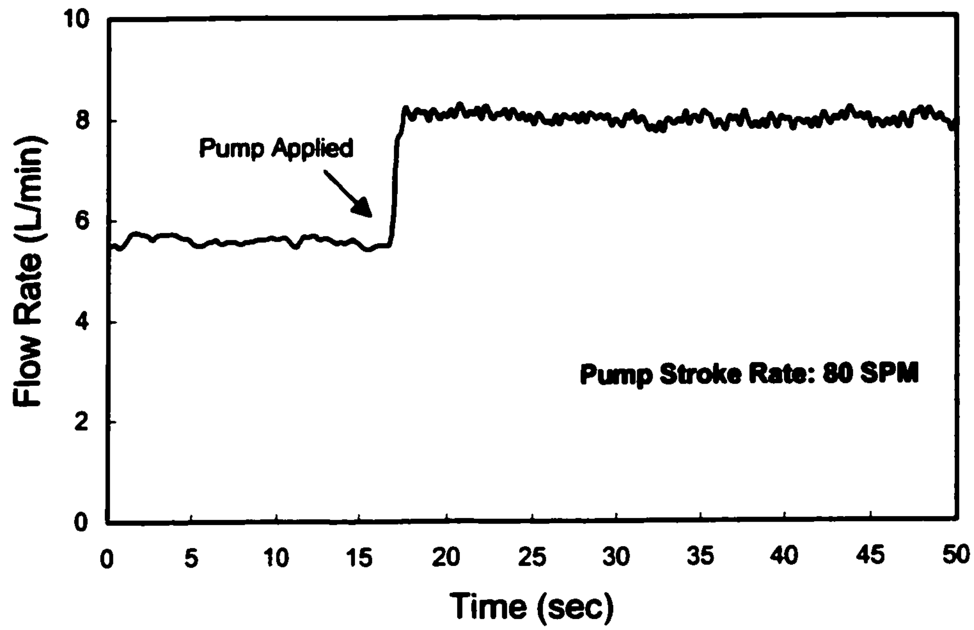


Figure 5-23 Flow Rate Adjusted by Pump at Speed 80SPM (Position 2)

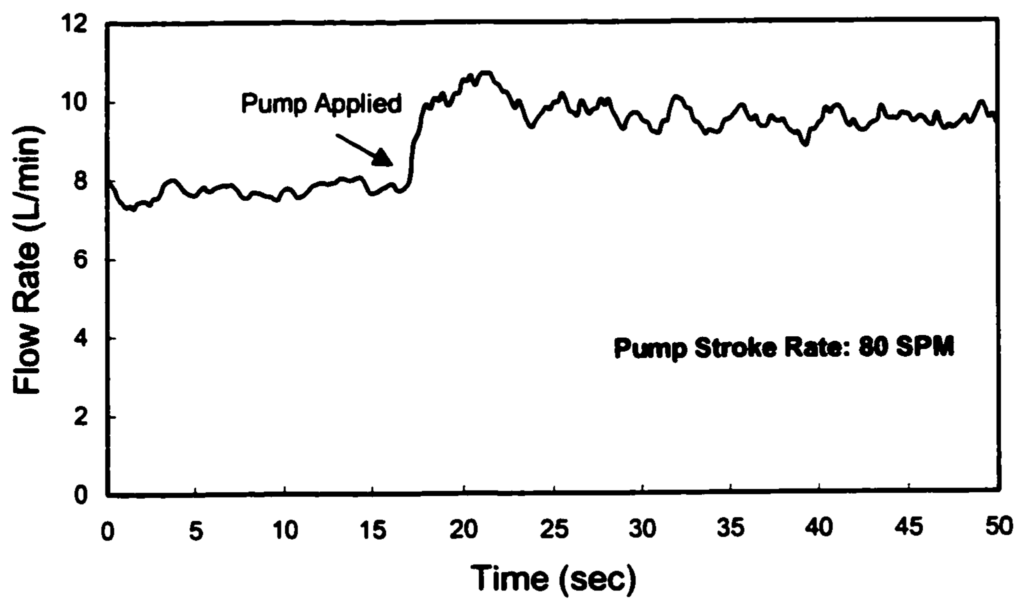


Figure 5-24 Flow Rate Adjusted by Pump at Speed 80SPM (Position 3)

5.3.2 Data Analysis and Observation for Configuration 1

In configuration 1, when intake valve handle is at position 1, the capability of pump as an actuator to adjust flow rates is summarized in Table 5-5. Due to the pulsed output of the pump, the values are presented as average flow rates.

Table 5-5 Adjustable Range by Pump with Valve Handle at Position 1

[redacted]	0	5	10	20	30	40	50	60	70	80
[redacted]	3.79	4.43	4.92	5.57	5.94	5.98	5.87	5.87	5.87	5.68

Figure 5-25 shows the adjustable flow rate range by the pump when the valve handle is at position 1.

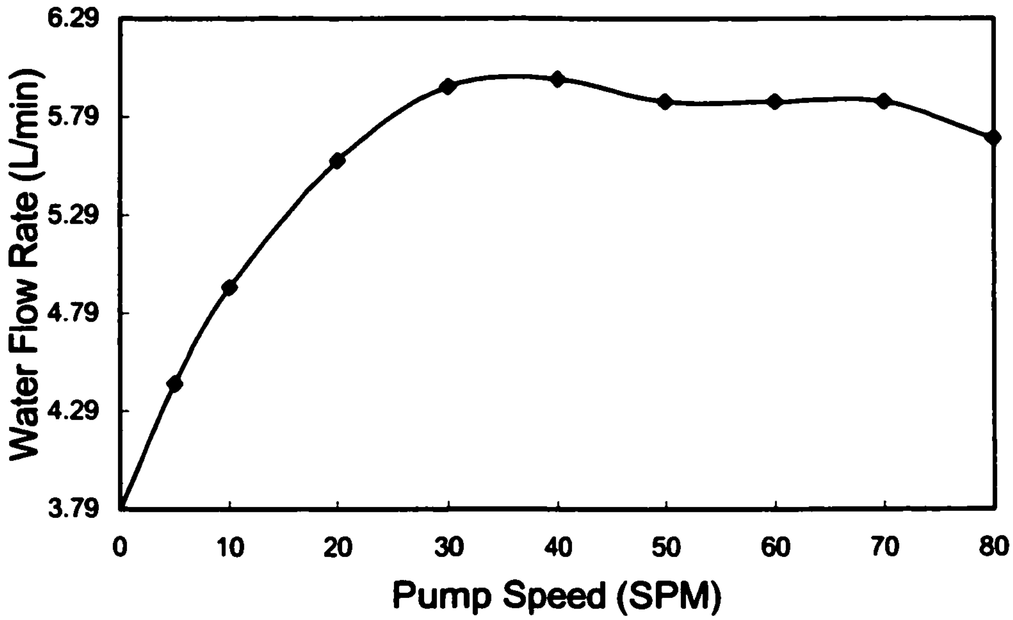


Figure 5-25 Adjustable Flow Rate Range by Pump (Position 1)

The capability of pump as an actuator to adjust the flow rate is summarized in Table 5-6 for the intake valve handle at position 2.

Table 5-6 Adjustable Range by Pump with Valve Handle at Position 2

[redacted]	0	5	10	20	30	40	50	60	70	80
	5.68	6.10	6.44	7.16	7.69	7.99	8.10	8.06	7.99	7.99

Figure 5-26 shows the adjustable flow rate range by the pump when the valve handle is at position 2.

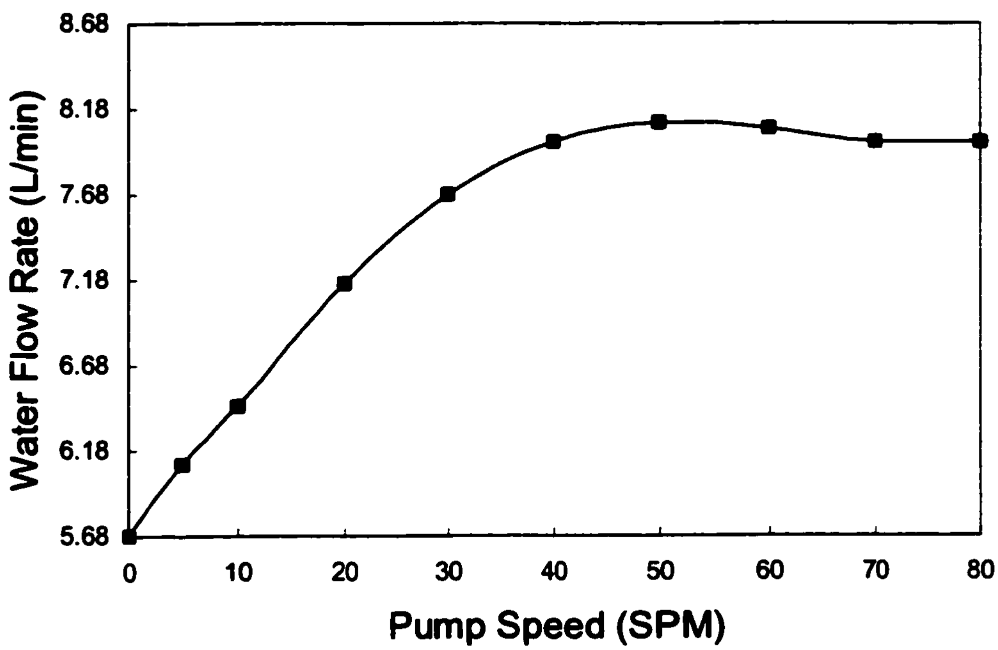


Figure 5-26 Adjustable Flow Rate Range by Pump (Position 2)

The capability of pump as an actuator to adjust the flow rate is summarized in Table 5-7 for the intake valve handle at position 3.

Table 5-7 Adjustable Range by Pump with Valve Handle at Position 3

[redacted]	0	5	10	20	30	40	50	60	70	80
[redacted]	7.57	7.91	8.10	8.48	8.90	9.31	9.73	9.88	9.81	9.50

Figure 5-27 shows the adjustable flow rate range by the pump when the valve handle is at position 3.

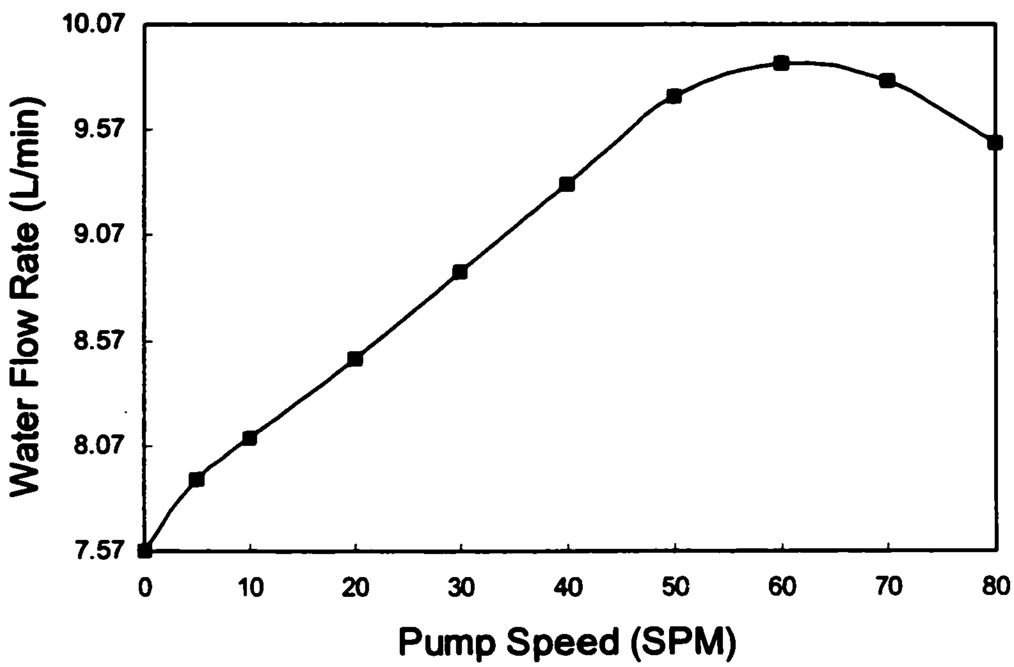


Figure 5-27 Adjustable Flow Rate Range by Pump (Position 3)

5.3.3 Sample Experimental Data with Configuration 2

Figure 5-28 shows the water flow rates with varying pump speed for configuration 2.

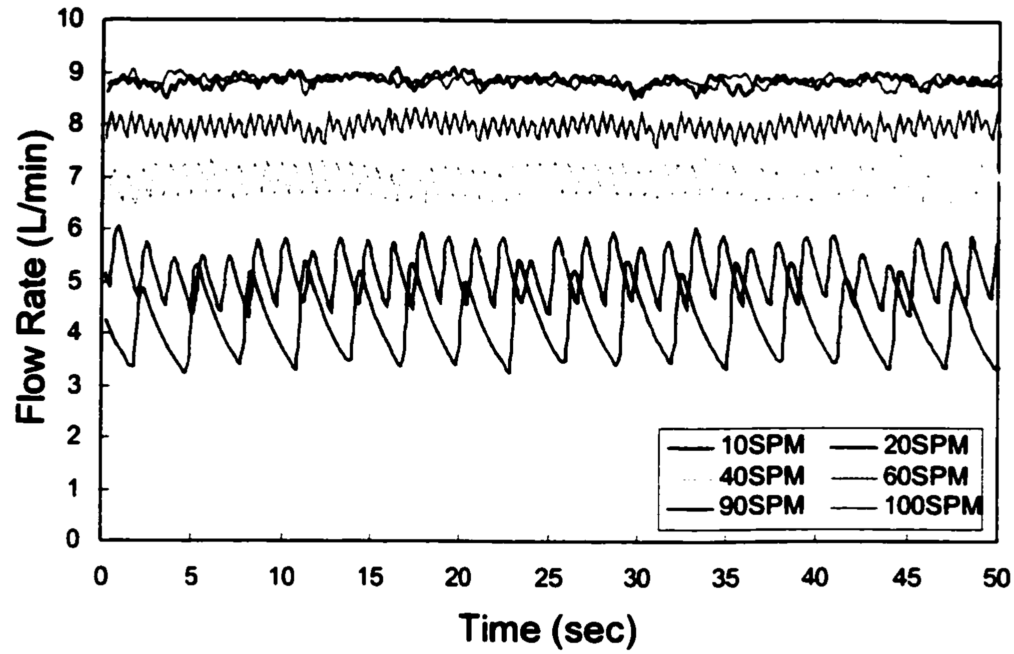


Figure 5-28 Pump Effectiveness on Flow Rate with Configuration 2

5.3.4 Data Observation for Configuration 2

The capability of the pump to adjust the flow rate in configuration 2 is shown in Table 5-8. Figure 5-29 shows the adjustable range by the pump in configuration 2.

Table 5-8 Adjustable Range by Pump with Configuration 2

Pump Speed (SPM)	10	20	30	40	50	60	70	80	90	100	110	120	130
Average Flow Rate (L/min)	4.23	5.18	6.00	6.92	7.70	7.97	8.46	8.71	8.84	8.85	8.78	8.76	8.77

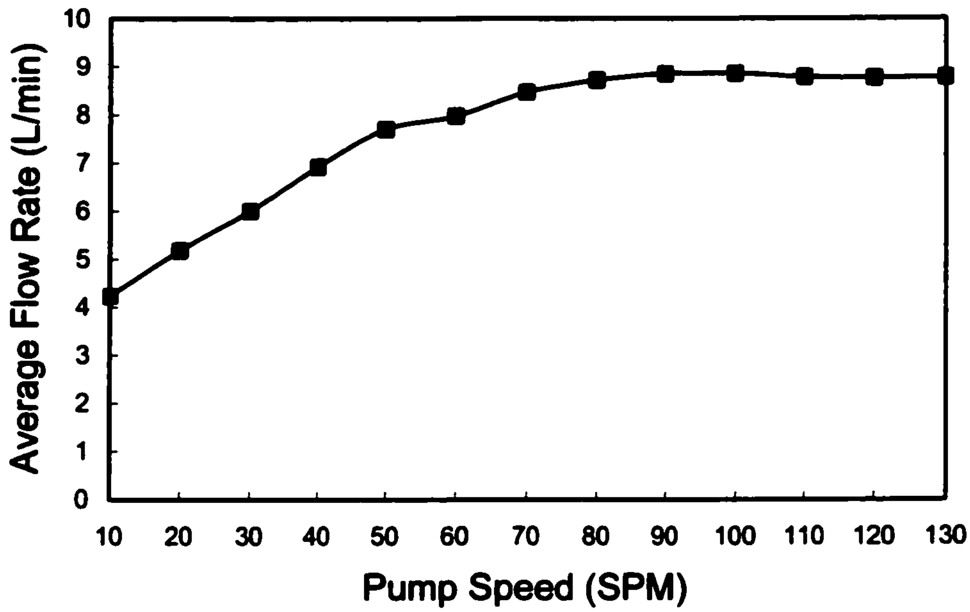


Figure 5-29 Adjustable Flow Rate Range by Pump (Configuration 2)

5.3.5 Conclusion for Experiment C

In configuration 1, the pump is unable to block water. The pump only increases water flow rates by around 1.89L/min (0.5GPM) regardless of the position of the intake valve handle. In configuration 2, the adjustable flow rate range obtained by changing the pump speed is from 4.16L/min (1.1GPM) to 8.71L/min (2.3GPM).

5.4 Summary

In this chapter, numerous experiments have been conducted with the lab simulator, and the experimental results presented. Observation and conclusions based on experimental data are reported.

Chapter 6

Adding Control Functionality to the Existing DAS

6.1 Introduction to Die Temperature Control

The conventional approach to thermal management of dies is based on trial and error and the experience of the operator. However, as industries become more competitive, there is an ever-increasing need to develop a more systematic approach to manage the die temperature. Conventionally, when significant thermal defects are produced, the water lines are manually adjusted. The action of an experienced operator does improve the situation; however, it requires frequent process monitoring. There is no immediate feedback on the temperature until it is reflected in the scrap rates, at which point it is too late to correct the problem.

There are three types of temperature controllers, which use direct temperature feedback from the die. They are on-off, proportional and PID controllers. There are a number of papers [15,16] discussing the use of an on/off controller to control die temperature by varying water line flow rates with an on/off solenoid valve. The on-off controller is the simplest form of temperature controller. For die temperature control, the solenoid valve is fully open to let water flow through when the temperature is above the set point, and closed below the set point. The on-off controller cannot achieve control precision and process temperature will be cycling continuously.

Booth [17] and Peterson [18] proposed varying the cycle time based on cavity surface temperature feedback. This is a proportional control; it is designed to eliminate the cycling associated with on-off control. It varies the ratio of "on" time to "off" time to control the water line flow rate. At the set point, the solenoid valve ON:OFF ratio is 1:1. If the temperature deviates from the set point, the on-time and off-time vary in proportion to the temperature difference. If temperature is below the set point, the valve will be fully closed longer; if the temperature is above the set point, the valve will be opened longer. This control scheme has a very slow response time and may slow production to unacceptably low levels.

Bishenden [19] uses a Proportional-Integral-Differential (PID) control algorithm to control die temperature. The proportional, integral and derivative terms must be individually tuned for particular system using trial and error. It provides the best control results among the three controller types.

6.2 Fuzzy Logic Control Algorithm

6.2.1 Introduction to Fuzzy Logic Controller

During the past several years, fuzzy logic has emerged as one of the most active and successful methods for developing sophisticated control systems. Recent applications of fuzzy control [20] include water quality control, automatic train operation systems, elevator control, automobile transmission control, and vehicle anti-lock brake system (ABS) control. No paper has been presented on the application of fuzzy logic algorithms to die casting process control.

There are a number of reasons to consider a fuzzy logic approach to control die temperature. It is found that the fuzzy logic controller requires less memory and executes faster than the PID controller [11]. In other words, an 8-bit fuzzy system may perform as well (same steady-state error and response time) as a 16-bit PID system. It is also more robust. The fuzzy logic approach is more intuitive, following more closely the way a human being would control the system. It is easy to modify an existing fuzzy control system for a new problem. Therefore, if the framework exists, rapid prototyping is possible.

"A fuzzy logic controller provides a means of converting a linguistic control strategy based on expert knowledge into an automatic control strategy" [21]. With the aid of fuzzy logic, complex control may be achieved in amazingly simple, easily maintained and inexpensive controllers. The control system output is determined by control rules. For example, control rules for the die insert temperature control include variables such as the die insert temperature and the water flow rate. The control signal may be determined by following the control rule: if the temperature of the die insert is too high, increase the pump speed to increase cooling water flow rate. Expert knowledge about the physical plant (in this case, the physical plant is the die insert) is needed before designing a fuzzy-logic controller.

6.2.2 Fuzzy- logic Controller Design Steps

Assume that the goal of control is to achieve the desired temperature range in the desired die insert.

The first step of designing a fuzzy-logic controller is to choose the feedback signals and actuating signals. For example, the die temperature is chosen as the controller feedback signal. The pump is the actuator of the system. The controller is able to drive the die temperature to the desired range by adjusting pump speed.

The second step is to select the inputs and outputs. Knowledge about how the physical plant operator is critical in this step. In the die temperature control system, two variables can be employed as controller inputs **E** and **D**:

$$\mathbf{E} = T_s - T$$

E is temperature error; T_s is the desired die temperature range; T is the actual temperature of die insert.

$$\mathbf{D} = T(n) - T(n-1)$$

D is the change in die temperature; T(n) is the instantaneous die temperature; T(n-1) is the previously sampled die temperature.

ΔN is the output of the controller, which is the change of pump speed.

The third step is to choose the fuzzy input and output membership sets. Each crisp input and output are divided into three regions. Three fuzzy membership sets are defined for temperature error E and die temperature change D.

Hot	True if die temperature T is above desired range
OK	True if die temperature T is in the desired range
Cold	True if die temperature T is below the desired temperature
Down	True if die temperature T is decreasing with time
Constant	True if die temperature T remains the same
Up	True if die temperature T is increasing

Three fuzzy output membership sets are defined for output ΔN:

Decrease	True if pump speed should be decreased
Same	True if pump speed should remain the same
Increase	True if pump speed should be increased

The fourth step is to choose functions for the conversion of inputs to the input membership variable.

The fifth step is to create the fuzzy rules. Intuition is used as a starting point. The fuzzy rules are summarized in Table 6-1.

Table 6-1 Fuzzy Rules for Die Temperature Control

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Same	Increase	Increase
[illegible]	Decrease	Same	Increase
[illegible]	Decrease	Decrease	Same

The sixth step is defuzzification. It is converting the true/false fuzzy output variable to controller output variable ΔN. The pump speed is controlled by control signal $N(n)=N(n-1)+\Delta N$.

6.3 Integrating Fuzzy Control to the Existing DAS

The software presented in Chapter 2 has a pump control sub-function module. However, it applies an ON/OFF control algorithm. The fuzzy-logic controller can be added to the pump control module. A variable M can be added to the software. When M is set to 1, fuzzy control mode is active; otherwise the on/off pump control mode is active. Figure 6-1 shows the modified flowchart of the pump control module.

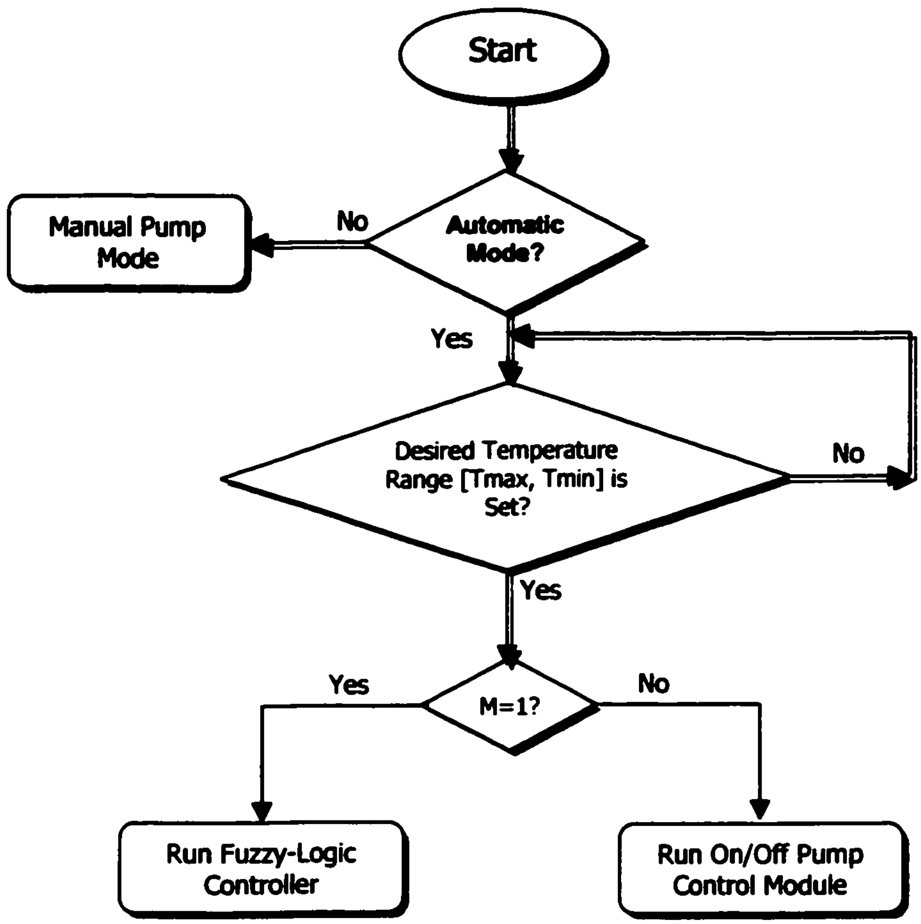


Figure 6-1 Flowchart of Pump Control Module

6.4 Summary

This chapter has provided a brief review of control methods that have been proposed for die temperature control. In particular, an introduction to fuzzy logic control has been presented, and the design steps of a fuzzy logic temperature controller have been discussed. The method for integrating a fuzzy logic controller to the PC-based data acquisition system has been explained.

Chapter 7

Summary and Conclusions

7.1 Summary

In this thesis, a die casting process simulator has been built in the laboratory. Comparisons between the simulator and real die casting processes have been discussed.

A PC-based data acquisition system for die casting processes has been designed and implemented. This data acquisition system has three channels for temperature signals and one channel for a flow rate signal, which can be displayed in graphical format and a direct numerical value format. In addition, this system has a built-in pump control module, which allows the system to implement simple flow rate control by controlling the pump speed. It has two operation modes: manual mode and automatic mode. Users can select between these two operation modes. The details of hardware selection, design and software development have been given in this thesis. Also, the performance of the system has been evaluated.

Experiments have been designed and conducted with the lab simulator in support of the objectives of this project. Valuable experimental data have been acquired and observations made.

Steps for designing a fuzzy-logic die temperature controller have been presented in this thesis. A method for integrating the fuzzy-logic controller to the existing data acquisition system has been explained.

7.2 Conclusions

The following conclusions can be drawn based on experimental data and observations.

1) Higher internal water flow rates cause lower die temperatures.
2) Higher internal water flow rates increase heat flux along the cooling waterline (X-direction) during the die closing stage. However, this effect does not seem significant because it is within the limits of measurement error.
3) Heat flux in the Z-direction is a function of cooling time and internal water flow rates. The higher the applied water flow rate, the less time the die insert takes to reach maximum heat flux. In the first 10 seconds after cooling begins, larger water flow rates cause much larger heat flux in Z-direction.

4) The time for temperature of the outlet water to reach the steady state becomes shorter as the water flow rates are higher. The steady state temperature of the outlet water tends to be higher when a lower water flow rate is applied.
5) The total waterline heat removal rate changes with cooling time and water flow rates. In the first 3 seconds of cooling, heat removal rates are significantly higher when applied water flow rates are higher. However, these higher heat removal rates decrease with an increase in cooling time.
6) When using the city water supply, the selected pump is able to increase water flow rates approximately 1.89L/min (0.5GPM). When using a water tank, the adjustable flow rate range achieved by changing the pump speed is from 4.16L/min (1.1GPM) to 8.71L/min (2.3GPM).

Chapter 8

Suggestions for Future Work

It is important to design a control system that can be executed on a regular and periodic rate when developing a digital control system. The operating system (Windows 98) installed on the computer used in our system is a general-purpose operating system that supports multi-tasking (task swapping). However, it does not have real-time performance, which means the latency (defined as the difference between the instant of time on which the task should have started (or finished) and the instant of time on which it actually did) [11] is unpredictable. For example, assuming the sampling period is set at 100ms, Windows 98 is unable to guarantee data will be sampled every 100ms. If another task, such as saving data, is required by the user at the same time, the delay is even worse. This delay varies with the number of other tasks being performed. One of the solutions to this problem is to use a real-time operating system instead of a general-purpose operation system. There are a variety of real-time operating systems commercially available, such as VxWorks from Wind River systems, QNX real-time operating system from QNX Software Systems, and RTLinux from Finite State Machine Labs Inc. Another solution is to develop a dedicated microcontroller-based system, which uses an industry standard, such as RS232, to communicate with the computer.

The fuzzy-logic die temperature controller appears worthy of implementation. Accordingly, the performance of the fuzzy-logic controller should be studied.

A more detailed theoretical analysis should be performed based on experimental data that has been acquired. Additionally, numerical modeling of the die temperature should be performed.

References

[1] The North American Die Casting Association (NADCA), http://www.diecasting.org/faq/introduction/, March 2002.

[2] Y. Chu, Private Communication with Ryobi Die Casting (USA) Inc., October 2001.

[3] Jonathan Papai and Carroll Mobley, "Die Thermal Fields and Heat Fluxes During Die Casting of 380 Aluminum Alloy in H-13 Steel Dies", NADCA Congress and Exposition Detroit, Paper No. Detroit-T91-OC1, October 1991.

[4] Shou-Shing Hsieh, "Transient Thermal Analysis of the waterlines effect in the die casting dies", Appl. Math. Modelling, Vol. 13, pp. 282-289, May 1989.

[5] C.W. Nelson, "A Study of Die Casting Water Line Variables", 5th National Die Casting Congress, Detroit, MI., Technical Paper 53, November 1968.

[6] P. Thukkaram, "Heat Transfer in Die Casting Dies", 6th SDCE International Die Casting Congress, Paper No. 61, November 1970.

[7] S.J. Vargo, A.B. Draper, and J.K, Sprinkle, "Waterline Location within a Die Casting Die", 13th SDCE International Die Casting Congress, Paper No. G-T85-066, June 1985.

[8] S. Bounds, K. Davey, and S. Hinduja, "An Experimental and Numerical Investigation into the Thermal Behavior of the Pressure Die Casting Process", Transactions of the ASME, Vol. 122, pp. 90-99, February 2000.

[9] Cyberresearch Inc., http://www.cyberresearch.com, September 2001.

[10] Omega, http://www.omega.com/temperature, September 2001.

[11] Jonathan W. Valvano, "Embedded Microcomputer System - Real Time Interfacing", Brooks/Cole, Pacific Grove, CA., 2000.

[12] John R. Taylor, "An Introduction to Error Analysis", University Science Books, Mill Valley, CA., 1982.

[13] The Database of Magwasoft Technologies Inc. April 2001.

[14] Chemical Hazards Response Information System (CHRIS), http:// www.chrismanual.com/Intro/prop.htm, April 2001.

[15] W.D. Kaiser, S.D. Sanders, and P.D.Frost, "The Ilzro-Battelle Multichannel Temperature Controller", 7th SDCE International Die Casting Congress, Paper No. 5172, October 1972.

[16] B.K. Dent, R. Fifer, "Production Operation with the Ilzro-Battelle Die Temperature Controller", 7th SDCE International Die Casting Congress, Paper No. 5572, October 1972.

[17] S.E. Booth, "A Die Temperature-cycle Time Controller", 6th SDCE International Die Casting Congress, Paper No. 54, November 1970.

[18] A.P. Peterson, "Thermocycling Control of Aluminum Die Casting Machines", 8th SDCE International Die Casting Exposition and Congress, Paper No. G-T75-024, March 1975.

[19] W. Bishenden, R. Bhola, "Die Temperature Control", 20th SDCE International Die Casting Exposition and Congress, Paper No. T99-051, November 1999.

[20] Chuen Chien Lee, "Fuzzy Logic in Control Systems: Fuzzy Logic Controller, Part I", IEEE Trans. Syst. Man Cybern., Vol. 20, pp. 404-415, March/April 1990.

[21] Chuen Chien Lee, "Fuzzy Logic in Control Systems: Fuzzy Logic Controller, Part II", IEEE Trans. Syst. Man Cybern., Vol. 20, pp. 419-433, March/April 1990.

[22] Frank P. Incropera and David P. Dewitt, "Introduction to Heat Transfer", John Wiley &Sons, Canada Ltd., Etobicoke, Ontario, 1990.

[23] Ernest O. Doebelin, "Measurement Systems: Application and Design", McGraw-Hill, Inc., New York, 1990.

[24] Herbert Schildt, "Turbo C/C++: the Complete Reference", McGraw-Hill, Inc., Berkeley, CA., 1992.

[25] Lindon C. Thomas, "Heat Transfer – Professional Version", Capstone Publishing Corporation, Tulsa, Okla., 1999.

Appendix A

Revised Thermocouple Reference Table for Type K

This appendix contains a revised thermocouple reference table for type K. The desired temperature range is from 0°C to 600°C. Thermocouple type K is subject to limits of error. For standard material, the limits of error are 2.2°C or 0.75% above 0°C whichever is greater. For special material, the limits of error are 1.1°C or 0.4% whichever is greater. Table shows the thermoelectric voltage output in millivolts with a reference junction at 0°C.

0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357
0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758
0.798	0.838	0.897	0.919	0.960	1.000	1.041	1.081	1.122	1.163
1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571
1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982
2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395
2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810
2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225
3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640
3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055
4.096	4.138	4.179	4.220	4.262	4.303	4.344	4.385	4.427	4.468
4.509	4.550	4.591	4.633	4.674	4.715	4.756	4.797	4.838	4.879
4.920	4.961	5.002	5.043	5.084	5.124	5.165	5.206	5.247	5.288
5.328	5.369	5.410	5.450	5.491	5.532	5.572	5.613	5.653	5.694
5.735	5.775	5.815	5.856	5.896	5.937	5.977	6.017	6.058	6.098
6.138	6.179	6.219	6.259	6.299	6.339	6.380	6.420	6.460	6.500
6.540	6.580	6.620	6.660	6.701	6.741	6.781	6.821	6.861	6.901
6.941	6.981	7.021	7.060	7.100	7.140	7.180	7.220	7.260	7.300
7.340	7.380	7.420	7.460	7.500	7.540	7.579	7.619	7.659	7.699
7.739	7.779	7.819	7.859	7.899	7.939	7.979	8.019	8.059	8.099
8.138	8.178	8.218	8.258	8.298	8.338	8.378	8.418	8.458	8.499
8.539	8.579	8.619	8.659	8.699	8.739	8.779	8.819	8.860	8.900
8.940	8.980	9.020	9.061	9.101	9.141	9.181	9.222	9.262	9.302
9.343	9.383	9.423	9.464	9.504	9.545	9.585	9.626	9.666	9.707
9.747	9.788	9.828	9.869	9.909	9.950	9.991	10.031	10.072	10.113
10.153	10.194	10.235	10.276	10.316	10.357	10.398	10.439	10.480	10.520
10.561	10.602	10.643	10.684	10.725	10.766	10.807	10.848	10.889	10.930
10.971	11.012	11.053	11.094	11.135	11.176	11.217	11.259	11.300	11.341
11.382	11.423	11.465	11.506	11.547	11.588	11.630	11.671	11.712	11.753
11.795	11.836	11.877	11.919	11.960	12.001	12.043	12.084	12.126	12.167

12.209	12.250	12.291	12.333	12.374	12.416	12.457	12.499	12.540	12.582
12.624	12.665	12.707	12.748	12.790	12.831	12.873	12.915	12.956	12.998
13.040	13.081	13.123	13.165	13.206	13.248	13.290	13.331	13.373	13.415
13.457	13.498	13.540	13.582	13.624	13.665	13.707	13.749	13.791	13.833
13.874	13.916	13.958	14.000	14.042	14.084	14.126	14.167	14.209	14.251
14.293	14.335	14.377	14.419	14.461	14.503	14.545	14.587	14.629	14.671
14.713	14.755	14.797	14.839	14.881	14.923	14.965	15.007	15.049	15.091
15.133	15.175	15.217	12.259	15.301	15.343	15.385	15.427	15.469	15.511
15.554	15.596	15.638	15.680	15.722	15.764	15.806	15.849	15.891	15.933
15.975	16.017	16.059	16.102	16.144	16.186	16.228	16.270	16.313	16.355
16.397	16.439	16.482	16.524	16.566	16.608	16.651	16.693	16.735	16.778
16.820	16.862	16.904	16.947	16.989	17.031	17.074	17.116	17.158	17.201
17.243	17.285	17.328	17.370	17.413	17.455	17.497	17.540	17.582	17.624
17.667	17.709	17.752	17.794	17.837	17.879	17.921	17.964	18.006	18.049
18.091	18.134	18.176	18.218	18.261	18.303	18.346	18.388	18.431	18.473
18.516	18.558	18.601	18.643	18.686	18.728	18.771	18.813	18.856	18.898
18.941	18.983	19.026	19.068	19.111	19.154	19.196	19.239	19.281	19.324
19.366	19.409	19.451	19.494	19.537	19.579	19.622	19.664	19.707	19.750
19.792	19.835	19.877	19.920	19.962	20.005	20.048	20.090	20.133	20.175
20.218	20.261	20.303	20.346	20.389	20.431	20.474	20.516	20.559	20.602
20.644	20.687	20.730	20.772	20.815	20.857	20.900	20.943	20.985	21.028
21.071	21.113	21.156	21.199	21.241	21.284	21.326	21.369	21.412	21.454
21.497	21.540	21.582	21.625	21.668	21.710	21.753	21.796	21.838	21.881
21.924	21.966	22.009	22.052	22.094	22.137	22.179	22.222	22.265	22.307
22.350	22.393	22.435	22.478	22.521	22.563	22.606	22.649	22.691	22.734
22.776	22.819	22.862	22.904	22.947	22.990	23.032	23.075	23.117	23.160
23.203	23.245	23.288	23.331	23.373	23.416	23.458	23.501	23.544	23.586
23.629	23.671	23.714	23.757	23.799	23.842	23.884	23.927	23.970	24.012
24.055	24.097	24.140	24.182	24.225	24.267	24.310	24.353	24.395	24.438
24.480	24.523	24.565	24.608	24.650	24.693	24.735	24.778	24.820	24.863
24.905	24.948	24.990	25.033	25.072	25.118	25.160	25.203	25.245	25.288

Appendix B

10,000 Readings of Die Insert Temperature T

This appendix contains the experimental results used to detect the noise range of the entire system. At room temperature with no heating and no cooling, the die insert temperature, T, has been measured 10,000 times. The 10, 000 readings (°C) are recorded here. The data is described by the following information.

Maximum recorded value: 31.2°C

Minimum recorded value: 28.7°C

Mean value: 29.7°C

Standard variation: 0.41°C

30.5	30.5	29.9	29.3	29.3	29.9	28.7	29.9	28.7	30.5	29.3	30.5	29.9	29.9	29.3	29.9	29.3	30.5	28.7	28.7
29.3	28.7	29.9	30.5	29.3	30.5	30.5	28.7	30.5	29.3	29.3	29.9	28.7	30.5	29.3	29.9	29.3	28.7	29.9	29.9
29.3	28.7	28.7	29.3	29.9	29.3	29.9	29.9	29.9	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.9	30.5	30.5
30.5	29.9	29.9	28.7	29.9	29.3	28.7	30.5	28.7	30.5	29.9	29.9	29.9	29.3	29.9	29.3	29.3	30.5	28.7	29.3
28.7	29.9	30.5	30.5	28.7	30.5	29.9	29.3	29.9	29.9	28.7	30.5	28.7	30.5	28.7	30.5	29.3	29.3	29.9	29.3
29.9	28.7	29.3	30.5	29.9	29.3	30.5	29.3	30.5	28.7	30.5	29.3	29.3	29.9	29.9	29.9	30.5	29.3	30.5	30.5
29.9	29.9	29.3	28.7	30.5	29.3	29.3	30.5	29.3	29.3	30.5	29.3	30.5	28.7	30.5	29.3	29.9	30.5	29.3	29.9
28.7	30.5	30.5	29.9	29.3	30.5	29.3	29.9	29.3	30.5	29.3	30.5	29.3	29.9	28.7	30.5	28.7	29.9	29.3	29.3
29.9	28.7	29.3	30.5	29.3	29.9	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.9	29.9	28.7	30.5	29.9
30.5	29.9	29.3	29.3	30.5	28.7	29.3	30.5	29.3	29.3	30.5	28.7	30.5	28.7	30.5	28.7	30.5	29.9	29.3	30.5
28.7	30.5	29.9	29.3	29.3	29.9	28.7	29.9	29.3	30.5	28.7	29.9	29.3	29.9	28.7	29.9	29.3	30.5	29.3	28.7
29.3	29.3	29.9	30.5	28.7	29.9	30.5	28.7	30.5	29.3	29.3	29.9	28.7	30.5	29.3	30.5	29.3	28.7	29.9	29.9
30.5	28.7	28.7	29.3	29.9	29.3	29.9	29.9	29.9	28.7	30.5	28.7	29.9	29.3	30.5	29.3	30.5	29.3	29.9	30.5
29.9	30.5	29.9	28.7	29.9	29.3	28.7	30.5	28.7	30.5	29.9	29.9	30.5	29.3	29.9	29.3	29.3	30.5	28.7	29.3
28.7	29.9	30.5	29.9	28.7	30.5	29.3	29.3	29.9	29.9	28.7	30.5	28.7	30.5	28.7	30.5	29.3	29.3	29.9	29.3
30.5	28.7	29.3	29.9	29.3	29.9	30.5	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.9	29.3	30.5	28.7	30.5	30.5
29.9	29.9	29.3	28.7	30.5	29.3	28.7	30.5	28.7	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.9	30.5	29.3	29.9
28.7	30.5	30.5	29.9	29.3	29.9	29.3	29.9	29.3	30.5	29.3	30.5	29.3	29.9	28.7	30.5	28.7	29.9	29.3	28.7
29.9	28.7	29.9	29.9	29.3	29.9	30.5	29.3	30.5	29.3	29.9	29.3	29.3	29.9	29.3	29.9	29.9	28.7	30.5	30.5
30.5	29.3	28.7	29.3	30.5	28.7	29.9	30.5	29.9	29.3	30.5	28.7	30.5	28.7	30.5	29.3	30.5	30.5	29.9	30.5
28.7	30.5	29.9	29.3	29.9	29.9	28.7	29.9	29.3	30.5	29.3	29.9	29.9	29.3	29.3	29.9	29.3	30.5	28.7	29.3
29.3	29.3	29.9	30.5	28.7	30.5	30.5	28.7	29.9	29.3	29.3	30.5	28.7	30.5	29.3	29.9	29.3	29.3	30.5	29.3
30.5	29.3	28.7	29.3	30.5	29.3	29.9	29.9	29.9	28.7	30.5	28.7	30.5	29.3	30.5	29.3	30.5	29.3	30.5	30.5
29.3	30.5	29.3	28.7	30.5	29.3	28.7	30.5	28.7	30.5	29.9	29.9	30.5	29.3	29.9	29.3	29.3	30.5	28.7	29.3
28.7	29.9	30.5	30.5	28.7	30.5	29.9	29.3	29.9	30.5	28.7	30.5	28.7	30.5	28.7	31.2	28.7	29.3	29.9	29.3
29.9	28.7	29.3	29.9	29.3	29.9	30.5	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.9	29.3	30.5	29.3	30.5	30.5
29.9	29.9	29.3	28.7	30.5	28.7	29.3	30.5	29.3	29.3	29.9	29.3	30.5	28.7	29.9	28.7	29.9	30.5	29.3	29.9
28.7	30.5	30.5	29.9	29.3	29.9	29.3	29.9	29.3	30.5	28.7	30.5	29.3	29.9	28.7	30.5	28.7	29.9	29.3	28.7
29.3	29.3	29.9	30.5	29.3	29.9	30.5	29.3	30.5	29.3	29.9	29.9	29.3	30.5	29.3	29.9	29.9	28.7	30.5	29.9
30.5	29.3	28.7	29.3	30.5	28.7	29.9	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	29.3	30.5	29.9	29.3	30.5
29.3	30.5	29.9	29.3	29.9	29.9	28.7	29.9	28.7	30.5	29.3	29.9	29.9	29.3	29.3	29.9	29.3	29.9	29.3	28.7
28.7	29.3	29.9	30.5	28.7	29.9	30.5	28.7	29.9	29.9	29.3	30.5	28.7	30.5	29.3	30.5	29.3	29.3	29.9	29.3
30.5	29.3	28.7	29.9	29.9	28.7	29.9	29.9	29.9	28.7	30.5	28.7	29.9	29.3	30.5	29.3	30.5	29.3	30.5	30.5
29.3	30.5	29.3	28.7	30.5	29.3	28.7	30.5	28.7	30.5	29.3	29.3	30.5	29.3	29.9	29.3	29.9	30.5	28.7	29.3
28.7	29.9	30.5	30.5	29.3	30.5	29.9	29.3	29.9	29.9	28.7	30.5	28.7	30.5	29.3	30.5	28.7	29.3	29.9	29.3
30.5	28.7	29.3	29.9	29.3	29.3	30.5	29.3	29.9	28.7	29.9	29.3	29.9	29.9	29.9	29.3	30.5	29.3	30.5	30.5
30.5	29.9	29.3	28.7	30.5	29.3	29.3	30.5	28.7	29.9	29.9	29.3	30.5	28.7	30.5	28.7	29.9	30.5	29.3	29.9
28.7	30.5	30.5	29.9	29.3	30.5	29.3	29.3	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	28.7	29.9	29.3	28.7
29.3	28.7	29.3	30.5	29.3	30.5	30.5	28.7	30.5	29.3	29.3	29.9	29.3	30.5	29.3	29.9	29.9	28.7	30.5	29.9
30.5	29.3	28.7	28.7	30.5	29.3	29.9	30.5	29.3	29.3	30.5	29.3	30.5	28.7	30.5	28.7	30.5	29.9	29.9	29.9
29.3	30.5	30.5	29.3	29.9	29.9	28.7	30.5	28.7	30.5	29.3	30.5	29.9	29.3	29.3	29.9	29.3	30.5	29.3	29.3
29.3	29.9	29.9	30.5	28.7	30.5	30.5	28.7	30.5	29.9	29.3	30.5	28.7	30.5	29.3	30.5	28.7	28.7	29.9	29.3
30.5	28.7	28.7	29.3	29.9	29.3	29.9	29.9	29.9	28.7	30.5	29.3	29.9	29.3	30.5	29.3	30.5	29.3	29.9	30.5
29.3	29.9	29.9	28.7	29.9	29.3	28.7	30.5	28.7	29.9	29.9	29.3	29.9	29.3	29.9	29.3	29.3	30.5	28.7	29.3
29.3	29.9	30.5	29.9	29.3	30.5	29.9	29.3	29.9	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.3	29.3	29.3	29.3

29.9	29.3	29.3	29.9	29.9	29.9	30.5	29.3	30.5	28.7	29.9	29.3	29.3	29.9	29.9	29.9	29.9	29.3	30.5	30.5
29.9	29.9	29.3	28.7	30.5	29.3	29.3	30.5	29.3	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9
28.7	30.5	30.5	29.9	29.3	29.9	29.3	29.9	29.3	30.5	28.7	30.5	29.3	29.9	28.7	30.5	28.7	29.9	29.3	28.7
29.9	29.3	29.9	30.5	28.7	29.9	30.5	28.7	30.5	29.3	29.3	29.9	28.7	30.5	29.3	30.5	29.9	28.7	30.5	29.9
30.5	29.3	28.7	29.3	30.5	28.7	29.9	29.9	29.3	29.3	30.5	28.7	30.5	28.7	30.5	28.7	30.5	29.9	29.9	30.5
29.3	30.5	30.5	29.3	29.9	29.3	28.7	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.3	29.9	29.3	30.5	28.7	29.3
29.3	29.3	30.5	30.5	28.7	30.5	30.5	29.3	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	29.3	29.3	29.9	29.3
30.5	29.3	28.7	29.9	29.9	29.3	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	30.5	29.3	30.5	29.3	30.5	30.5
29.9	29.9	29.9	28.7	30.5	29.3	28.7	30.5	28.7	29.9	29.9	29.3	30.5	28.7	29.9	29.3	29.9	30.5	28.7	29.9
28.7	29.9	30.5	30.5	28.7	30.5	29.3	29.3	29.9	29.9	28.7	30.5	28.7	30.5	28.7	30.5	28.7	29.3	29.3	28.7
29.9	28.7	29.3	29.9	29.9	29.9	30.5	29.3	30.5	29.3	29.9	29.3	29.3	29.9	29.9	29.3	30.5	29.3	30.5	30.5
30.5	29.9	29.3	28.7	30.5	28.7	29.3	30.5	29.3	29.3	29.9	29.3	30.5	28.7	30.5	29.3	29.9	30.5	29.3	29.9
28.7	29.9	30.5	29.9	29.3	29.9	29.3	29.9	29.3	30.5	29.3	30.5	29.3	29.9	29.3	30.5	29.3	29.9	29.3	28.7
29.3	29.3	29.9	30.5	28.7	29.9	30.5	28.7	30.5	29.3	29.3	29.9	29.3	30.5	29.3	30.5	29.3	28.7	29.9	29.9
30.5	29.3	28.7	29.3	30.5	28.7	29.9	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.9	29.9	30.5
29.3	30.5	30.5	29.3	29.9	29.9	28.7	30.5	28.7	30.5	29.9	29.9	29.9	29.3	29.3	29.9	29.3	30.5	28.7	28.7
29.3	29.3	30.5	30.5	28.7	30.5	29.9	28.7	29.9	29.9	28.7	30.5	28.7	30.5	29.3	30.5	29.3	28.7	29.9	29.3
30.5	28.7	29.3	29.9	29.9	29.3	30.5	29.3	29.9	29.3	30.5	29.3	29.9	29.3	30.5	29.3	30.5	29.3	30.5	30.5
29.3	30.5	29.9	28.7	29.9	29.3	28.7	30.5	28.7	30.5	29.9	29.3	30.5	29.3	29.9	29.3	29.9	30.5	28.7	29.3
29.3	29.9	30.5	30.5	29.3	30.5	29.9	29.3	29.9	31.2	28.7	30.5	28.7	30.5	28.7	30.5	29.3	29.3	29.3	28.7
29.9	28.7	29.3	30.5	29.3	29.9	30.5	29.3	30.5	29.3	29.9	29.3	29.3	29.9	29.9	29.3	30.5	28.7	30.5	29.9
29.9	29.9	29.3	28.7	30.5	28.7	29.3	30.5	29.3	29.3	30.5	28.7	30.5	28.7	30.5	28.7	30.5	30.5	29.3	29.9
28.7	30.5	30.5	29.3	29.3	29.9	29.3	29.9	28.7	30.5	28.7	29.9	29.9	29.9	29.3	30.5	28.7	29.9	29.3	28.7
29.3	29.3	29.9	30.5	29.3	29.9	30.5	28.7	30.5	29.3	29.3	29.9	28.7	30.5	29.3	30.5	29.9	28.7	30.5	29.9
30.5	29.3	28.7	29.3	30.5	28.7	29.3	29.9	29.3	28.7	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.9	29.9	30.5
29.3	30.5	29.9	29.3	29.9	29.3	28.7	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.9	29.3	30.5	28.7	28.7
29.3	29.3	29.9	30.5	28.7	30.5	29.9	28.7	29.9	29.9	28.7	30.5	28.7	30.5	28.7	30.5	29.3	29.3	29.9	29.3
29.9	28.7	28.7	29.3	29.9	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	29.9	29.3	30.5	29.3	29.9	30.5
29.9	30.5	29.9	28.7	30.5	29.3	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.3	30.5	29.3	29.9	30.5	29.3	29.3
28.7	29.9	30.5	29.9	28.7	30.5	29.3	29.3	29.3	30.5	28.7	30.5	29.3	30.5	28.7	31.2	28.7	29.3	29.3	29.3
29.9	29.3	29.3	30.5	29.3	29.9	30.5	29.3	30.5	28.7	29.9	29.3	29.3	29.9	29.9	29.3	30.5	28.7	30.5	30.5
31.2	29.9	29.3	29.3	30.5	28.7	29.3	30.5	29.3	29.9	30.5	29.3	30.5	28.7	30.5	28.7	30.5	30.5	29.3	29.9
29.3	30.5	30.5	29.9	29.3	29.9	29.3	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	29.9	28.7	29.9	29.3	28.7
29.3	29.3	29.9	30.5	28.7	29.9	30.5	28.7	30.5	29.3	29.3	29.9	28.7	30.5	29.3	30.5	29.3	28.7	30.5	29.9
30.5	29.3	28.7	29.3	30.5	28.7	29.9	29.9	29.9	28.7	30.5	28.7	29.9	29.3	30.5	28.7	30.5	29.9	29.9	30.5
29.3	30.5	29.9	29.3	29.9	29.9	28.7	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.9	29.3	30.5	28.7	29.3
29.3	29.9	30.5	30.5	28.7	30.5	30.5	29.3	29.9	29.9	28.7	30.5	28.7	30.5	28.7	30.5	28.7	29.3	29.9	29.3
30.5	28.7	28.7	29.3	29.9	29.3	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	30.5	29.3	30.5	29.3	30.5	30.5
29.9	29.9	29.9	28.7	30.5	28.7	29.3	30.5	29.3	29.9	29.9	29.3	30.5	29.3	29.9	29.3	29.9	30.5	28.7	29.9
28.7	29.9	30.5	29.9	29.3	30.5	29.3	29.3	29.3	30.5	28.7	30.5	29.3	30.5	29.3	30.5	28.7	29.3	29.3	29.3
29.9	28.7	29.3	30.5	29.3	29.9	30.5	28.7	30.5	29.3	29.9	29.9	29.9	29.9	29.3	29.9	29.9	28.7	30.5	30.5
30.5	29.9	29.3	28.7	30.5	28.7	29.3	29.9	29.3	29.3	30.5	28.7	30.5	28.7	30.5	28.7	30.5	30.5	29.3	29.9
29.3	30.5	30.5	29.3	29.9	29.9	29.3	29.9	29.3	30.5	29.3	30.5	29.3	29.9	29.3	29.9	29.3	30.5	28.7	28.7
29.3	29.3	29.9	30.5	29.3	30.5	30.5	28.7	30.5	29.3	29.3	29.9	28.7	30.5	29.3	29.9	29.3	28.7	30.5	29.3
30.5	29.3	28.7	29.3	30.5	28.7	29.9	29.9	29.9	28.7	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.9	29.9	30.5

29.3	30.5	29.9	29.3	30.5	29.9	28.7	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.3	30.5	28.7	29.3
29.3	29.3	30.5	30.5	28.7	30.5	29.9	28.7	29.9	29.9	29.3	30.5	28.7	30.5	28.7	30.5	29.3	29.3	29.9	29.3
30.5	28.7	28.7	29.9	29.9	29.3	30.5	29.3	29.9	28.7	30.5	29.3	29.9	29.3	29.9	28.7	30.5	29.9	30.5	30.5
29.9	29.9	29.3	28.7	29.9	29.3	28.7	30.5	28.7	29.9	29.9	29.3	30.5	29.3	30.5	29.3	29.9	30.5	28.7	29.9
28.7	30.5	30.5	29.9	29.3	29.9	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	28.7	29.9	29.9	28.7
29.9	28.7	28.7	30.5	29.3	29.9	30.5	28.7	29.9	29.3	29.9	29.9	29.3	29.9	29.9	29.9	29.9	28.7	30.5	29.9
29.9	29.3	29.3	29.3	30.5	28.7	29.3	29.9	29.3	29.3	30.5	28.7	30.5	28.7	30.5	28.7	30.5	30.5	29.3	30.5
29.3	30.5	30.5	29.3	29.3	29.9	29.3	29.9	29.3	30.5	29.3	30.5	29.9	29.9	29.3	29.9	28.7	30.5	28.7	28.7
29.3	29.3	29.3	30.5	28.7	29.9	30.5	28.7	30.5	29.3	29.3	30.5	29.3	30.5	29.3	30.5	29.3	28.7	30.5	29.9
30.5	29.3	28.7	29.3	30.5	28.7	29.9	29.9	29.9	28.7	31.2	28.7	29.9	29.3	30.5	29.3	30.5	29.9	29.9	30.5
29.3	30.5	30.5	29.3	29.9	29.3	28.7	30.5	28.7	29.9	29.3	29.9	29.9	29.3	29.9	29.9	29.3	30.5	28.7	29.3
29.3	29.3	29.9	30.5	28.7	30.5	29.9	29.3	29.9	29.9	29.3	30.5	28.7	30.5	28.7	30.5	29.3	29.3	29.9	29.3
30.5	28.7	29.3	29.9	29.9	29.3	30.5	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.9	29.3	30.5	29.3	29.9	30.5
29.9	29.9	29.9	28.7	30.5	29.3	29.3	30.5	29.3	29.9	29.9	29.3	30.5	29.3	29.9	28.7	29.9	30.5	28.7	29.9
28.7	29.9	30.5	30.5	29.3	30.5	29.3	29.3	29.3	30.5	28.7	30.5	29.3	30.5	29.3	30.5	28.7	29.3	29.3	28.7
29.9	28.7	29.3	30.5	29.3	29.9	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.9	29.9	28.7	30.5	30.5
30.5	29.3	29.3	29.3	30.5	28.7	29.3	30.5	29.3	29.9	30.5	28.7	30.5	28.7	29.9	28.7	30.5	30.5	29.3	29.9
29.3	30.5	30.5	29.9	29.9	29.9	29.3	29.9	29.3	30.5	29.3	30.5	29.9	29.9	29.3	29.9	28.7	29.9	28.7	28.7
29.3	28.7	29.9	30.5	28.7	30.5	30.5	28.7	30.5	29.3	29.3	29.9	28.7	30.5	28.7	30.5	29.3	28.7	30.5	29.3
30.5	29.3	28.7	29.3	30.5	28.7	29.9	29.9	29.9	28.7	30.5	28.7	29.9	29.3	30.5	28.7	30.5	29.9	29.9	30.5
29.3	30.5	30.5	29.3	30.5	29.3	28.7	30.5	28.7	30.5	29.3	29.9	30.5	29.3	29.9	29.9	29.3	30.5	28.7	29.3
28.7	29.9	30.5	30.5	29.3	30.5	29.9	29.3	29.9	29.9	28.7	30.5	28.7	30.5	28.7	30.5	28.7	29.3	29.9	29.3
29.9	28.7	29.3	29.9	29.9	29.3	30.5	29.3	30.5	28.7	29.9	29.3	29.9	29.3	29.9	29.3	30.5	29.3	30.5	30.5
29.9	29.9	29.3	28.7	30.5	29.3	28.7	30.5	28.7	29.9	29.9	29.3	30.5	28.7	30.5	28.7	29.9	30.5	29.3	29.9
28.7	29.9	30.5	29.9	29.3	30.5	29.3	29.9	29.3	30.5	28.7	30.5	29.3	30.5	29.3	30.5	28.7	29.3	29.3	28.7
29.9	28.7	29.3	30.5	29.3	29.9	30.5	29.3	30.5	29.3	29.9	29.9	28.7	29.9	29.3	29.9	29.9	28.7	30.5	30.5
30.5	29.9	29.3	28.7	30.5	28.7	29.3	30.5	29.9	29.3	30.5	28.7	30.5	28.7	30.5	28.7	30.5	29.9	29.3	29.9
29.3	30.5	30.5	29.3	29.3	29.9	28.7	29.9	29.3	30.5	29.3	30.5	29.9	29.9	29.3	29.9	29.3	29.9	28.7	28.7
29.3	29.3	29.9	30.5	28.7	30.5	30.5	28.7	30.5	29.9	29.3	30.5	28.7	30.5	29.3	30.5	29.3	28.7	30.5	29.9
30.5	29.3	28.7	29.3	29.9	29.3	29.9	29.3	29.9	28.7	30.5	29.3	30.5	29.3	30.5	28.7	30.5	29.9	29.9	30.5
29.3	30.5	29.9	29.3	29.9	29.3	28.7	30.5	28.7	30.5	29.3	29.3	30.5	29.3	29.9	29.9	29.3	30.5	28.7	29.3
29.3	29.3	30.5	30.5	29.3	30.5	29.9	29.3	29.9	30.5	28.7	30.5	29.3	30.5	28.7	31.2	28.7	29.3	29.9	29.3
30.5	28.7	28.7	29.9	29.3	29.3	30.5	29.3	30.5	28.7	29.9	29.3	29.9	29.9	29.9	29.3	30.5	29.3	30.5	30.5
29.9	30.5	29.3	28.7	30.5	29.3	28.7	30.5	29.3	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.9	30.5	29.3	29.9
28.7	29.9	30.5	29.9	29.3	30.5	29.3	29.3	29.3	30.5	29.3	30.5	29.3	30.5	29.3	30.5	28.7	29.9	29.3	28.7
29.9	28.7	29.3	29.9	29.3	29.9	30.5	28.7	31.2	29.3	29.9	29.9	29.3	29.9	29.3	29.9	29.9	28.7	30.5	29.9
29.9	29.9	29.3	28.7	30.5	28.7	29.3	29.9	29.9	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.9	29.3	30.5
28.7	30.5	30.5	29.3	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.3	29.9	29.3	29.9	28.7	28.7
29.3	29.3	29.9	30.5	28.7	30.5	30.5	28.7	30.5	29.9	29.3	30.5	28.7	30.5	29.3	30.5	29.3	28.7	30.5	29.9
30.5	29.3	28.7	29.3	29.9	28.7	29.9	29.9	30.5	28.7	30.5	28.7	29.9	29.3	30.5	28.7	30.5	29.3	30.5	30.5
29.3	30.5	29.9	29.3	30.5	29.3	28.7	30.5	28.7	29.9	29.9	29.3	30.5	29.3	29.9	29.3	29.3	30.5	28.7	29.3
28.7	29.3	30.5	30.5	28.7	30.5	29.9	29.3	29.9	29.9	28.7	30.5	29.3	30.5	28.7	30.5	29.3	29.3	29.9	29.3
30.5	29.3	29.3	29.9	29.3	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.3	29.9	29.9	29.3	30.5	29.3	30.5	30.5
29.9	29.9	29.3	28.7	30.5	29.3	29.3	30.5	29.3	29.3	29.9	29.3	30.5	29.3	30.5	28.7	29.9	30.5	29.3	29.9
28.7	30.5	30.5	29.9	29.3	29.9	29.3	29.9	29.3	30.5	28.7	30.5	29.3	29.9	28.7	29.9	28.7	29.3	29.3	28.7

29.9	28.7	29.3	30.5	29.3	29.9	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.9	29.9	28.7	30.5	29.9
30.5	29.9	29.3	29.3	30.5	28.7	29.3	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.9	29.3	30.5
29.3	30.5	30.5	29.3	29.9	29.9	28.7	30.5	28.7	30.5	28.7	29.9	29.3	29.9	29.3	29.9	28.7	29.9	28.7	28.7
29.3	29.3	29.9	30.5	28.7	30.5	30.5	28.7	29.9	29.9	29.3	30.5	28.7	30.5	29.3	30.5	29.3	29.3	30.5	29.3
30.5	29.3	28.7	29.3	29.9	29.3	29.9	29.9	30.5	28.7	30.5	29.3	29.9	29.3	30.5	29.3	30.5	29.3	29.9	30.5
29.3	30.5	29.9	29.3	30.5	29.3	28.7	30.5	28.7	29.9	29.9	29.3	30.5	29.3	29.9	29.3	29.3	30.5	28.7	29.3
28.7	29.9	30.5	30.5	29.3	30.5	29.9	29.3	29.9	29.9	28.7	30.5	29.3	30.5	28.7	30.5	29.3	29.3	29.9	29.3
29.9	28.7	28.7	29.9	29.3	29.3	30.5	29.3	30.5	28.7	29.9	29.3	29.3	30.5	29.9	29.3	30.5	29.3	30.5	30.5
29.9	30.5	29.3	28.7	30.5	29.3	29.3	30.5	29.3	29.9	30.5	29.3	30.5	28.7	30.5	29.3	29.9	30.5	29.3	29.9
28.7	29.9	30.5	29.9	29.3	29.9	29.3	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	29.9	28.7	29.3	29.3	28.7
29.9	28.7	29.3	30.5	28.7	29.9	30.5	28.7	30.5	29.3	29.9	29.9	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.9
30.5	29.9	29.3	28.7	30.5	28.7	29.3	30.5	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	30.5	29.9	29.3	29.9
28.7	30.5	30.5	29.3	29.9	29.9	28.7	29.9	29.3	30.5	29.3	29.9	29.9	29.3	29.3	29.9	29.3	29.9	29.3	28.7
29.3	29.3	29.9	30.5	28.7	30.5	30.5	28.7	29.9	29.9	28.7	30.5	28.7	30.5	28.7	30.5	29.3	28.7	30.5	29.3
30.5	29.3	28.7	29.3	29.9	29.3	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	29.9	28.7	30.5	29.3	29.9	30.5
29.3	30.5	29.9	29.3	30.5	29.3	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.3	29.9	29.3	29.3	29.9	28.7	29.3
28.7	29.3	30.5	30.5	29.3	30.5	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	28.7	29.3	29.9	28.7
30.5	28.7	28.7	29.9	29.3	29.3	30.5	29.3	30.5	29.3	29.9	29.3	29.3	29.9	29.9	29.3	30.5	29.3	30.5	30.5
29.9	29.9	29.3	28.7	30.5	28.7	28.7	30.5	29.3	29.3	30.5	28.7	30.5	29.3	30.5	28.7	29.9	31.2	29.3	29.9
28.7	30.5	30.5	29.9	29.3	30.5	29.3	29.9	29.3	30.5	29.3	30.5	29.3	29.9	29.3	30.5	29.3	29.3	29.3	28.7
29.9	29.3	29.3	30.5	29.3	29.9	30.5	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.3	29.9	29.9	29.3	30.5	29.9
30.5	29.9	29.3	29.3	30.5	28.7	29.3	29.9	29.9	29.3	30.5	28.7	30.5	28.7	30.5	28.7	30.5	30.5	29.3	30.5
28.7	30.5	30.5	29.3	29.9	29.9	28.7	30.5	28.7	30.5	29.3	29.9	29.9	29.9	29.9	29.9	29.3	30.5	28.7	28.7
29.3	28.7	29.9	30.5	28.7	30.5	29.9	28.7	29.9	29.9	29.3	30.5	28.7	30.5	28.7	30.5	29.3	28.7	29.9	29.3
30.5	29.3	28.7	29.3	29.9	29.3	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	29.9	29.3	30.5	29.9	30.5	30.5
29.9	30.5	29.9	29.3	30.5	29.3	28.7	30.5	28.7	29.9	29.9	29.3	30.5	29.3	30.5	29.3	29.9	30.5	28.7	29.3
28.7	29.3	30.5	30.5	29.3	30.5	29.9	29.3	29.3	29.9	28.7	30.5	29.3	30.5	28.7	30.5	28.7	29.3	29.3	29.3
29.9	28.7	29.3	29.9	29.3	29.3	30.5	29.3	30.5	29.3	29.9	29.3	29.3	29.9	29.9	29.3	29.9	29.3	30.5	29.9
29.9	29.9	29.3	28.7	30.5	28.7	29.3	30.5	29.3	29.3	29.9	29.3	30.5	28.7	30.5	28.7	29.9	30.5	29.3	29.9
28.7	29.9	30.5	29.9	29.3	30.5	29.3	29.3	29.3	30.5	28.7	30.5	29.3	29.9	29.3	30.5	29.3	29.9	29.3	29.3
29.9	28.7	29.3	30.5	29.3	29.9	30.5	28.7	30.5	29.3	29.9	29.9	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.9
30.5	29.9	28.7	29.3	29.9	28.7	29.9	29.9	29.9	28.7	30.5	28.7	30.5	29.3	30.5	28.7	30.5	30.5	29.9	30.5
29.3	30.5	30.5	29.3	29.9	29.9	28.7	29.9	28.7	29.9	29.3	29.9	30.5	29.3	29.9	29.9	29.3	29.9	28.7	29.3
28.7	29.3	29.9	30.5	28.7	30.5	30.5	28.7	29.9	29.9	29.3	30.5	28.7	30.5	29.3	30.5	29.3	28.7	30.5	29.3
30.5	29.3	28.7	29.3	29.9	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	30.5	29.9	30.5	29.9	30.5	30.5
29.9	30.5	29.9	28.7	30.5	29.3	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.3	30.5	29.3	29.3	30.5	29.3	29.3
28.7	29.9	30.5	29.9	28.7	30.5	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	29.3	30.5	29.3	29.3	29.9	29.3
30.5	28.7	28.7	29.9	29.3	29.3	29.9	29.3	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.9	30.5	29.3	30.5	29.9
29.9	29.9	29.9	28.7	30.5	29.3	29.3	29.9	29.3	29.3	30.5	29.3	30.5	28.7	29.9	28.7	29.9	30.5	29.3	29.9
28.7	30.5	29.9	29.9	29.3	30.5	29.3	29.9	29.3	30.5	29.3	30.5	29.3	29.9	29.3	29.9	29.3	29.9	29.3	28.7
29.3	28.7	29.3	30.5	28.7	29.9	30.5	28.7	30.5	29.3	29.3	30.5	28.7	30.5	28.7	29.9	29.9	29.3	30.5	29.9
30.5	29.3	29.3	28.7	29.9	29.3	29.3	29.9	29.9	28.7	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.9	29.3	29.9
29.3	30.5	30.5	29.3	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.9	29.3	30.5	28.7	29.3
29.3	29.3	29.9	30.5	28.7	30.5	30.5	29.3	29.9	29.9	28.7	30.5	28.7	30.5	29.3	30.5	29.3	29.3	29.9	29.3
30.5	29.3	29.3	29.3	29.9	29.3	29.9	29.3	30.5	28.7	29.9	29.3	29.9	29.3	29.9	29.3	30.5	29.9	29.9	30.5

29.9	30.5	29.9	29.3	30.5	29.3	28.7	30.5	29.3	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.9	30.5	28.7	29.3
28.7	29.3	30.5	30.5	28.7	30.5	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	29.3	30.5	28.7	29.3	29.9	29.3
29.9	28.7	29.3	29.9	29.3	29.3	30.5	29.3	30.5	28.7	29.9	29.3	29.3	29.9	29.3	29.9	30.5	29.3	30.5	30.5
29.9	29.9	29.3	28.7	30.5	29.3	29.3	30.5	29.3	29.3	30.5	29.3	30.5	28.7	30.5	29.3	30.5	30.5	29.3	29.9
28.7	30.5	30.5	29.9	29.3	30.5	29.3	29.9	29.3	30.5	28.7	29.9	29.9	29.9	29.3	29.9	28.7	29.9	28.7	28.7
29.3	28.7	29.3	30.5	28.7	29.9	30.5	28.7	30.5	29.9	29.3	29.9	28.7	30.5	29.3	29.9	29.9	28.7	30.5	29.9
30.5	29.3	29.3	29.3	29.9	28.7	29.3	29.9	30.5	29.3	30.5	29.3	30.5	29.3	30.5	28.7	30.5	29.9	29.9	30.5
29.3	30.5	30.5	29.3	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.9	30.5	29.3	29.9	29.9	29.3	30.5	28.7	29.3
29.3	29.3	29.9	30.5	28.7	30.5	30.5	29.3	29.9	29.9	28.7	30.5	28.7	30.5	28.7	30.5	29.3	28.7	29.9	29.3
30.5	29.3	28.7	29.3	29.9	29.3	29.9	29.3	30.5	28.7	29.9	29.3	29.9	29.3	29.9	29.3	30.5	29.3	30.5	30.5
29.9	30.5	29.9	28.7	29.9	29.3	28.7	30.5	28.7	29.9	29.9	29.3	30.5	29.3	30.5	29.3	29.9	30.5	28.7	29.3
28.7	29.9	29.9	30.5	29.3	30.5	29.9	29.3	29.3	30.5	28.7	30.5	29.3	29.9	28.7	30.5	29.3	29.3	29.9	28.7
30.5	28.7	28.7	29.9	29.3	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.9	29.9	29.9	28.7	30.5	29.9
30.5	29.9	29.3	28.7	30.5	28.7	29.3	30.5	29.9	29.3	30.5	28.7	30.5	28.7	30.5	29.3	29.9	30.5	29.3	29.9
28.7	30.5	29.9	29.9	29.9	30.5	29.3	29.9	28.7	30.5	28.7	30.5	29.9	29.9	29.3	30.5	28.7	29.9	29.3	28.7
29.3	28.7	29.3	30.5	28.7	29.9	30.5	28.7	29.9	29.3	29.3	30.5	29.3	30.5	28.7	30.5	29.9	28.7	30.5	29.9
30.5	29.9	29.3	29.3	29.9	26.7	29.9	29.9	29.9	28.7	30.5	28.7	29.9	28.7	30.5	29.3	30.5	29.9	29.9	30.5
29.3	30.5	30.5	29.3	30.5	29.9	28.7	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.9	29.3	29.9	28.7	29.3
29.3	29.3	29.9	30.5	28.7	30.5	29.9	29.3	29.9	29.9	28.7	30.5	28.7	30.5	28.7	30.5	29.3	29.3	29.9	29.3
30.5	29.3	28.7	29.3	29.3	29.3	30.5	29.9	30.5	28.7	30.5	29.3	29.3	29.3	29.9	29.3	30.5	29.3	30.5	30.5
29.9	30.5	29.9	29.3	30.5	29.3	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.3	30.5	29.3	29.9	30.5	28.7	29.9
28.7	29.9	30.5	29.9	29.3	30.5	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	29.3	30.5	29.3	29.3	29.3	28.7
29.9	29.3	28.7	29.9	29.3	29.3	30.5	29.3	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.3	30.5	29.3	30.5	29.9
30.5	29.9	29.3	28.7	30.5	29.3	28.7	30.5	29.9	28.7	30.5	28.7	30.5	28.7	30.5	28.7	30.5	31.2	29.3	29.9
28.7	30.5	30.5	29.9	29.9	30.5	29.3	29.9	28.7	30.5	29.3	29.9	29.9	29.9	29.3	29.9	29.3	29.9	29.3	28.7
29.3	28.7	29.3	30.5	28.7	29.9	30.5	28.7	30.5	29.3	29.3	30.5	28.7	30.5	29.3	30.5	29.9	28.7	30.5	29.9
30.5	29.3	29.3	29.3	29.9	28.7	29.9	29.9	29.9	28.7	30.5	28.7	29.9	29.3	30.5	28.7	30.5	29.9	29.9	30.5
29.3	30.5	30.5	29.3	30.5	29.9	28.7	30.5	28.7	29.9	29.3	29.3	29.9	29.3	29.9	29.3	28.7	30.5	28.7	29.3
29.3	29.3	29.9	30.5	28.7	30.5	30.5	29.3	29.9	30.5	29.3	30.5	29.3	30.5	28.7	30.5	29.3	28.7	29.9	29.3
30.5	29.3	28.7	29.9	29.3	29.3	29.9	29.3	30.5	28.7	29.9	29.3	29.9	29.3	29.9	29.3	30.5	29.9	30.5	30.5
29.9	30.5	29.9	28.7	30.5	29.3	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.3	29.9	29.3	29.3	30.5	29.3	29.9
28.7	29.9	30.5	30.5	29.3	30.5	29.9	29.9	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.3	29.9	29.9	28.7
29.9	28.7	28.7	29.9	28.7	29.9	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.9	30.5	29.3	30.5	30.5
30.5	29.9	29.3	28.7	30.5	28.7	29.3	29.9	29.9	29.3	30.5	29.3	29.9	28.7	30.5	28.7	30.5	30.5	29.3	30.5
28.7	30.5	30.5	29.9	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.9	29.9	29.9	28.7	29.9	29.3	28.7
29.3	28.7	29.3	30.5	29.3	29.9	30.5	28.7	30.5	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	28.7	30.5	29.3
30.5	29.3	29.3	29.3	29.9	28.7	29.9	29.9	29.9	29.3	30.5	28.7	29.9	28.7	29.9	28.7	30.5	29.9	29.9	30.5
29.3	30.5	30.5	29.3	30.5	29.3	28.7	30.5	28.7	29.9	29.3	29.3	30.5	29.3	29.9	29.9	29.3	30.5	28.7	29.3
29.3	29.3	29.9	30.5	28.7	30.5	29.9	29.3	29.9	29.9	28.7	30.5	28.7	30.5	28.7	30.5	29.3	28.7	29.9	29.3
29.9	28.7	28.7	29.3	29.3	29.3	29.9	29.3	30.5	28.7	30.5	29.3	29.3	29.3	29.9	28.7	30.5	29.3	30.5	30.5
29.3	30.5	29.9	28.7	30.5	29.3	28.7	30.5	29.3	29.3	30.5	29.3	30.5	28.7	30.5	29.3	29.9	30.5	29.3	29.9
28.7	29.9	29.9	29.9	29.3	30.5	29.9	29.9	29.3	30.5	28.7	30.5	29.9	30.5	28.7	30.5	28.7	29.3	29.3	28.7
29.9	28.7	29.3	30.5	29.3	29.9	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.9	29.9	29.3	30.5	29.9
30.5	29.9	29.3	28.7	30.5	29.3	29.3	30.5	29.9	29.3	30.5	28.7	30.5	28.7	30.5	28.7	29.9	30.5	29.3	29.9
28.7	30.5	30.5	29.3	29.9	30.5	29.3	29.9	28.7	30.5	29.3	29.9	29.9	29.9	29.3	29.9	28.7	29.9	29.3	29.3

29.3	28.7	29.3	30.5	28.7	29.9	30.5	28.7	30.5	29.9	29.3	30.5	29.3	30.5	29.3	29.9	29.9	29.3	30.5	29.3
30.5	29.3	29.3	29.3	29.9	29.3	29.9	29.9	30.5	28.7	30.5	29.3	29.9	29.3	30.5	28.7	31.2	29.9	29.9	30.5
29.3	30.5	30.5	28.7	30.5	29.9	28.7	30.5	28.7	29.9	29.3	29.3	30.5	29.3	29.9	29.9	29.3	30.5	28.7	29.3
28.7	29.3	29.9	30.5	28.7	30.5	30.5	29.3	29.3	29.9	28.7	30.5	29.3	30.5	28.7	30.5	29.3	29.3	29.9	29.3
30.5	28.7	28.7	29.9	29.3	29.3	29.9	29.3	30.5	28.7	30.5	29.3	29.3	29.3	29.9	29.3	30.5	29.3	30.5	30.5
29.9	30.5	29.9	28.7	30.5	29.3	28.7	30.5	29.3	29.3	29.9	28.7	30.5	29.3	30.5	29.3	29.9	30.5	29.3	29.9
28.7	29.9	30.5	29.9	29.9	30.5	29.3	29.3	29.3	30.5	28.7	30.5	29.3	30.5	29.3	30.5	29.3	29.3	29.3	29.3
29.9	28.7	28.7	30.5	29.3	29.9	30.5	28.7	30.5	29.3	29.3	29.9	28.7	29.9	29.3	29.9	29.9	29.3	30.5	29.9
30.5	29.9	29.3	29.3	30.5	28.7	29.3	29.9	29.9	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.9	29.3	30.5
29.3	30.5	30.5	29.3	29.9	30.5	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.9	29.3	29.9	28.7	29.9	28.7	28.7
29.3	29.3	29.3	30.5	28.7	29.9	30.5	28.7	29.9	29.9	29.3	30.5	28.7	30.5	28.7	30.5	29.9	28.7	30.5	29.3
30.5	29.9	28.7	29.3	29.9	28.7	29.9	29.9	29.9	28.7	30.5	29.3	29.9	29.3	30.5	29.3	31.2	29.9	29.9	30.5
29.3	30.5	30.5	29.3	30.5	29.9	28.7	30.5	29.3	29.9	29.9	29.9	30.5	29.3	29.9	29.9	29.3	29.9	28.7	29.3
29.3	29.3	29.9	30.5	29.3	30.5	29.9	28.7	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.3	28.7	29.9	29.3
30.5	29.3	28.7	29.9	29.3	29.3	30.5	29.3	31.2	28.7	29.9	29.9	29.3	29.3	29.9	29.3	30.5	29.3	30.5	30.5
29.9	30.5	29.9	28.7	30.5	29.3	29.3	30.5	29.3	29.3	29.9	28.7	30.5	29.3	30.5	29.3	29.9	30.5	29.3	29.9
29.3	29.9	30.5	29.9	29.3	30.5	29.3	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	30.5	28.7	29.3	29.3	28.7
29.9	28.7	29.3	29.9	29.3	29.9	30.5	28.7	30.5	29.3	29.9	29.9	28.7	30.5	29.3	29.9	29.9	28.7	30.5	29.3
30.5	29.9	29.3	28.7	29.9	28.7	29.3	29.9	29.9	29.3	30.5	28.7	30.5	28.7	30.5	28.7	29.9	30.5	29.3	30.5
29.3	30.5	30.5	29.3	29.9	30.5	29.3	29.9	28.7	30.5	29.3	29.9	29.9	29.9	29.3	29.9	28.7	29.3	28.7	28.7
29.3	29.3	29.3	30.5	28.7	29.9	30.5	28.7	29.9	29.9	29.3	30.5	28.7	29.9	28.7	30.5	29.3	28.7	29.9	29.3
30.5	29.3	29.3	29.3	29.9	28.7	29.9	29.3	29.9	28.7	30.5	29.3	29.9	29.3	30.5	29.3	30.5	29.9	29.9	30.5
29.3	30.5	30.5	28.7	30.5	29.9	28.7	30.5	28.7	29.9	29.9	29.3	30.5	29.3	29.9	29.3	29.3	30.5	28.7	29.3
28.7	29.3	29.9	30.5	29.3	30.5	29.9	29.3	29.3	29.9	28.7	30.5	29.3	30.5	28.7	30.5	29.3	28.7	29.9	28.7
29.9	29.3	28.7	30.5	29.3	29.3	30.5	29.3	30.5	28.7	29.9	29.3	29.3	29.3	29.3	29.3	30.5	29.3	30.5	30.5
29.9	30.5	29.9	28.7	30.5	29.3	29.3	30.5	29.3	29.3	29.9	29.3	30.5	28.7	29.9	29.3	29.9	30.5	29.3	29.9
28.7	29.9	30.5	29.9	29.9	30.5	29.3	29.9	28.7	30.5	28.7	29.9	29.3	30.5	29.3	30.5	28.7	29.3	29.3	28.7
29.9	28.7	29.3	30.5	28.7	29.9	30.5	28.7	30.5	29.3	29.3	30.5	28.7	29.9	29.3	29.9	30.5	29.3	30.5	29.9
30.5	29.9	29.3	28.7	30.5	28.7	29.3	29.9	29.9	29.3	30.5	28.7	30.5	28.7	30.5	28.7	29.9	30.5	29.3	30.5
29.3	29.9	30.5	29.9	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.9	28.7	29.9	29.3	29.3
29.3	28.7	29.3	30.5	28.7	29.9	30.5	29.3	29.9	29.9	29.3	30.5	28.7	30.5	28.7	29.9	29.9	28.7	29.9	29.3
30.5	29.3	28.7	29.3	29.9	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.9	28.7	30.5	29.3	30.5	29.9	29.9	30.5
29.9	30.5	30.5	29.3	30.5	29.9	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.3	29.9	29.3	29.3	30.5	28.7	29.3
28.7	29.3	29.9	30.5	29.3	30.5	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.3	28.7	29.9	28.7
30.5	28.7	28.7	29.9	29.3	29.3	30.5	29.3	30.5	29.3	29.9	29.9	29.3	29.9	29.9	29.3	30.5	29.3	30.5	30.5
30.5	29.9	29.9	28.7	30.5	29.3	28.7	29.9	29.3	29.3	30.5	29.3	30.5	28.7	30.5	28.7	29.9	30.5	29.3	29.9
28.7	29.9	30.5	29.9	29.3	30.5	29.3	29.9	29.3	30.5	29.3	30.5	29.3	29.9	29.3	30.5	28.7	29.3	29.3	29.3
29.9	28.7	29.3	30.5	29.3	29.9	30.5	29.3	30.5	29.3	29.3	29.9	29.3	30.5	29.3	29.9	29.9	28.7	30.5	29.9
30.5	29.9	29.3	28.7	30.5	28.7	29.3	29.9	29.9	29.3	30.5	28.7	30.5	29.3	30.5	28.7	29.9	30.5	29.9	30.5
28.7	30.5	30.5	29.3	29.9	30.5	28.7	30.5	28.7	30.5	29.3	29.9	30.5	29.9	29.3	29.9	28.7	29.9	28.7	29.3
29.3	29.3	29.9	30.5	28.7	29.9	30.5	28.7	29.9	29.9	29.3	30.5	28.7	30.5	29.3	30.5	29.3	28.7	29.9	29.3
30.5	29.3	28.7	29.3	29.9	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	29.9	28.7	30.5	29.9	29.9	30.5
29.9	30.5	30.5	29.3	30.5	29.9	29.3	30.5	28.7	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.3	30.5	29.3	29.3
28.7	29.3	30.5	30.5	29.3	30.5	29.9	29.9	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.3	29.3	29.9	29.3
30.5	29.3	28.7	29.9	29.3	29.3	30.5	29.3	30.5	29.3	29.9	29.9	29.3	29.9	29.9	29.3	30.5	29.9	30.5	29.9

29.9	29.9	29.9	28.7	30.5	29.3	28.7	29.9	29.3	29.3	30.5	28.7	30.5	28.7	30.5	28.7	29.9	30.5	29.3	29.9
28.7	29.9	30.5	29.9	29.3	30.5	29.3	29.9	28.7	30.5	28.7	29.9	29.9	29.9	29.3	30.5	28.7	29.3	29.3	28.7
29.9	28.7	29.3	29.9	28.7	29.9	30.5	28.7	30.5	29.3	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.9
30.5	29.3	29.3	29.3	30.5	29.3	29.3	29.9	29.9	29.3	30.5	28.7	30.5	28.7	30.5	28.7	30.5	30.5	29.9	30.5
29.3	30.5	30.5	29.3	29.9	30.5	29.3	30.5	28.7	29.9	29.3	29.9	29.9	29.3	29.9	29.9	29.3	29.9	28.7	29.3
29.3	29.3	29.3	30.5	28.7	29.9	30.5	29.3	29.9	29.9	29.3	30.5	29.3	30.5	28.7	30.5	29.3	28.7	29.9	29.3
30.5	29.3	29.3	29.3	29.9	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	29.9	29.3	30.5	29.9	30.5	30.5
29.3	30.5	30.5	28.7	30.5	29.9	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.3	29.9	29.3	29.3	30.5	28.7	29.3
28.7	29.3	29.9	30.5	29.3	30.5	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	29.3	30.5	29.3	28.7	29.9	28.7
29.9	29.3	28.7	29.9	29.3	29.3	30.5	29.3	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.9	30.5	29.3	30.5	30.5
30.5	30.5	29.9	28.7	30.5	29.3	29.3	30.5	29.3	29.3	30.5	29.3	30.5	28.7	30.5	28.7	29.3	30.5	29.3	29.9
28.7	29.9	30.5	29.9	29.3	30.5	29.3	29.9	28.7	30.5	28.7	30.5	29.9	29.3	29.3	30.5	28.7	29.3	29.3	28.7
29.9	28.7	28.7	30.5	28.7	29.9	30.5	28.7	30.5	29.9	29.9	29.9	28.7	30.5	29.3	29.9	29.9	28.7	30.5	29.9
30.5	29.9	29.3	29.3	30.5	28.7	29.3	29.9	29.9	29.3	30.5	28.7	29.9	28.7	30.5	28.7	30.5	30.5	29.3	30.5
29.3	30.5	30.5	29.3	30.5	29.9	29.3	30.5	28.7	30.5	29.9	29.3	29.9	29.9	29.9	29.9	28.7	29.9	29.3	29.3
29.3	29.3	29.3	30.5	28.7	29.9	30.5	29.3	29.9	29.9	29.3	30.5	28.7	30.5	28.7	30.5	29.3	28.7	29.9	29.3
30.5	29.9	28.7	29.3	29.9	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.3	29.3	29.9	29.3	30.5	29.9	29.9	30.5
29.9	30.5	30.5	29.3	30.5	29.3	28.7	30.5	28.7	29.9	30.5	29.3	30.5	28.7	30.5	29.3	29.3	30.5	28.7	29.3
28.7	29.3	29.9	30.5	29.3	30.5	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.3	29.3	29.9	28.7
29.9	29.3	28.7	29.9	29.3	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.9	30.5	29.3	30.5	29.9
29.9	30.5	29.9	28.7	30.5	29.3	28.7	30.5	29.3	29.3	30.5	28.7	30.5	28.7	30.5	28.7	29.9	30.5	29.3	29.9
28.7	29.9	30.5	29.9	29.3	30.5	29.3	30.5	28.7	30.5	29.3	30.5	29.9	29.9	29.3	29.9	28.7	29.3	29.3	28.7
29.9	28.7	29.3	30.5	28.7	29.9	30.5	28.7	29.9	29.9	29.3	29.9	28.7	30.5	29.3	29.9	29.9	28.7	30.5	29.9
30.5	29.9	29.3	29.3	30.5	28.7	29.3	29.9	29.9	28.7	30.5	28.7	29.9	28.7	30.5	28.7	30.5	30.5	29.9	30.5
29.3	30.5	30.5	29.3	29.9	29.9	29.3	30.5	28.7	29.9	29.3	29.3	30.5	29.3	29.9	29.9	28.7	29.9	28.7	29.3
29.3	29.3	29.3	30.5	28.7	30.5	30.5	29.3	29.3	29.9	28.7	30.5	28.7	30.5	28.7	30.5	29.3	28.7	29.9	29.3
30.5	29.3	28.7	29.3	29.9	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.3	29.3	29.9	29.3	30.5	29.9	30.5	30.5
29.9	30.5	30.5	28.7	30.5	29.3	29.3	30.5	29.3	29.3	30.5	29.3	30.5	29.3	30.5	29.3	29.3	30.5	28.7	29.9
28.7	29.9	29.9	30.5	29.3	30.5	29.9	29.9	29.3	30.5	28.7	30.5	29.3	30.5	29.3	30.5	29.3	28.7	29.3	28.7
29.9	29.3	28.7	29.9	29.3	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.9	30.5	29.3	30.5	29.9
30.5	29.9	29.3	28.7	30.5	29.3	29.3	30.5	29.3	29.3	30.5	28.7	30.5	28.7	30.5	29.3	29.9	30.5	29.3	29.9
28.7	29.9	30.5	29.9	29.3	30.5	29.3	29.9	28.7	30.5	29.3	29.9	29.9	29.9	29.3	29.9	29.3	29.9	29.3	28.7
29.9	28.7	29.3	30.5	28.7	29.9	30.5	28.7	30.5	29.9	29.3	30.5	28.7	29.9	29.3	29.9	29.9	28.7	30.5	29.9
30.5	29.9	29.3	29.3	30.5	29.3	29.9	29.9	30.5	28.7	30.5	28.7	29.9	29.3	30.5	28.7	29.9	29.9	29.9	30.5
29.3	30.5	30.5	29.3	30.5	29.9	29.3	30.5	28.7	29.9	29.9	29.3	30.5	29.3	29.9	29.9	28.7	29.9	28.7	29.3
29.3	29.3	29.3	30.5	29.3	29.9	30.5	29.3	29.9	29.9	28.7	30.5	29.3	30.5	28.7	30.5	29.3	28.7	29.9	29.3
30.5	29.3	29.3	29.3	29.9	28.7	29.9	29.3	30.5	28.7	29.9	29.3	29.9	29.3	29.9	29.3	30.5	29.9	30.5	30.5
29.9	30.5	29.9	29.3	30.5	29.3	28.7	30.5	29.3	29.3	29.9	28.7	30.5	29.3	30.5	29.3	29.3	30.5	29.3	29.3
28.7	29.3	29.9	29.9	29.3	30.5	29.9	29.9	29.3	30.5	28.7	30.5	29.3	30.5	29.3	30.5	29.3	28.7	29.3	28.7
29.9	29.3	28.7	29.9	29.3	29.3	30.5	28.7	30.5	28.7	29.9	29.3	29.3	29.9	29.3	29.3	30.5	29.3	30.5	29.9
29.9	30.5	29.9	28.7	30.5	29.3	28.7	29.9	29.9	29.3	30.5	29.3	30.5	29.3	30.5	28.7	29.9	30.5	29.3	29.9
28.7	29.9	30.5	29.9	29.9	30.5	29.3	29.9	29.3	30.5	28.7	29.9	29.9	29.9	29.3	29.9	28.7	29.3	29.3	28.7
29.3	29.3	29.3	30.5	28.7	29.9	30.5	28.7	30.5	29.3	29.3	30.5	28.7	30.5	29.3	30.5	29.9	28.7	30.5	29.9
30.5	29.9	29.3	29.3	29.9	28.7	29.3	29.9	29.9	28.7	30.5	28.7	29.9	28.7	30.5	28.7	30.5	30.5	29.9	30.5
28.7	30.5	30.5	29.3	30.5	29.9	28.7	30.5	28.7	29.9	29.3	29.3	29.9	29.3	29.9	29.3	28.7	30.5	28.7	29.3

28.7	29.3	29.3	30.5	28.7	29.9	29.9	28.7	29.3	29.9	29.3	30.5	28.7	30.5	28.7	30.5	29.3	29.3	29.9	29.3
30.5	29.3	28.7	29.9	29.3	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.3	29.3	29.9	29.3	30.5	29.9	30.5	30.5
29.9	30.5	30.5	28.7	30.5	29.9	28.7	30.5	29.3	29.3	30.5	28.7	30.5	28.7	30.5	29.3	29.3	30.5	28.7	29.9
28.7	29.3	29.9	30.5	29.3	30.5	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.9	28.7	30.5	28.7	28.7	29.3	28.7
29.9	29.3	28.7	30.5	29.3	29.3	30.5	28.7	30.5	29.3	29.9	29.9	28.7	29.9	29.3	29.9	30.5	29.3	30.5	30.5
30.5	29.9	29.9	28.7	30.5	29.3	29.3	29.9	29.9	29.3	30.5	28.7	30.5	28.7	30.5	28.7	29.9	30.5	29.3	30.5
28.7	29.9	30.5	29.9	29.9	30.5	29.3	29.9	28.7	30.5	29.3	29.9	29.9	29.9	29.3	30.5	28.7	29.9	29.3	28.7
29.9	28.7	29.3	30.5	29.3	29.9	30.5	29.3	29.9	29.9	29.3	30.5	28.7	30.5	28.7	30.5	29.9	29.3	29.9	29.9
30.5	29.9	29.3	29.3	29.9	29.3	29.9	29.9	30.5	28.7	30.5	29.3	29.9	29.3	30.5	28.7	30.5	30.5	29.9	30.5
29.3	30.5	30.5	28.7	29.9	29.9	28.7	30.5	28.7	29.9	29.3	29.3	30.5	29.3	29.9	29.9	29.3	29.9	28.7	29.3
29.3	29.3	29.9	30.5	29.3	30.5	29.9	29.3	29.3	30.5	29.3	30.5	29.3	30.5	28.7	30.5	29.3	28.7	29.9	29.3
30.5	29.3	29.3	29.9	29.9	28.7	29.9	28.7	30.5	28.7	30.5	29.9	29.3	29.3	29.9	29.3	29.9	29.9	30.5	30.5
29.9	30.5	29.9	28.7	30.5	29.9	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.3	30.5	29.3	29.3	30.5	29.3	29.9
28.7	29.3	29.9	29.9	29.3	30.5	29.9	29.9	29.3	30.5	28.7	30.5	29.3	31.2	29.3	30.5	28.7	29.3	29.3	28.7
29.9	29.3	28.7	29.9	29.3	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.9	30.5	29.3	30.5	29.9
29.9	30.5	29.9	28.7	30.5	29.3	29.3	30.5	29.9	29.3	30.5	28.7	30.5	28.7	30.5	28.7	29.9	30.5	29.3	30.5
29.3	29.9	30.5	29.9	29.9	30.5	29.3	29.9	28.7	29.9	29.3	29.9	29.9	29.9	29.3	29.9	28.7	29.9	29.3	29.3
29.9	28.7	29.3	30.5	28.7	29.9	30.5	29.3	29.9	29.9	29.3	30.5	28.7	30.5	28.7	29.9	29.9	28.7	30.5	29.3
30.5	29.9	29.3	29.3	29.9	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	29.9	28.7	30.5	30.5	29.9	30.5
29.3	30.5	30.5	29.3	30.5	29.9	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.3	29.9	29.9	29.3	30.5	29.3	29.3
29.3	29.3	29.3	30.5	28.7	30.5	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.3	29.3	29.9	29.3
30.5	29.3	29.3	29.9	29.9	28.7	30.5	29.3	30.5	29.3	29.9	29.9	29.3	29.3	29.3	29.3	30.5	29.9	30.5	30.5
29.9	30.5	29.9	28.7	30.5	29.3	28.7	30.5	29.3	29.3	29.9	28.7	30.5	28.7	30.5	29.3	29.3	30.5	29.3	29.9
28.7	29.3	30.5	29.9	29.3	30.5	29.9	29.9	28.7	30.5	28.7	30.5	29.3	29.9	29.3	30.5	28.7	29.3	29.3	28.7
29.9	28.7	28.7	30.5	29.3	29.3	30.5	28.7	30.5	29.3	29.3	30.5	28.7	29.9	29.3	29.9	30.5	29.3	30.5	29.9
30.5	30.5	29.9	29.3	30.5	29.3	29.3	29.9	29.9	29.3	30.5	29.3	30.5	28.7	30.5	28.7	29.9	30.5	29.3	30.5
29.3	29.9	30.5	29.3	29.9	30.5	29.3	30.5	28.7	29.9	29.3	29.9	29.9	29.9	29.3	29.9	28.7	29.3	29.3	29.3
29.3	28.7	29.3	30.5	28.7	29.9	30.5	29.3	29.9	29.9	29.3	30.5	29.3	30.5	28.7	30.5	29.3	28.7	30.5	29.3
30.5	29.9	29.3	29.3	29.9	29.3	29.9	29.9	30.5	28.7	30.5	29.3	29.9	28.7	30.5	28.7	30.5	30.5	29.9	30.5
29.3	30.5	30.5	29.3	30.5	29.9	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.3	29.9	29.3	28.7	29.9	28.7	29.3
29.3	28.7	29.9	30.5	29.3	30.5	30.5	28.7	29.3	29.9	28.7	30.5	29.3	30.5	29.3	30.5	29.3	28.7	29.9	29.3
30.5	29.3	29.3	29.9	29.3	28.7	30.5	28.7	30.5	29.3	30.5	29.3	29.3	29.3	29.9	29.3	30.5	29.9	31.2	30.5
29.9	30.5	29.9	28.7	30.5	29.3	28.7	30.5	29.3	29.3	29.9	28.7	30.5	29.3	30.5	29.3	29.9	30.5	29.3	30.5
28.7	29.3	30.5	29.9	29.3	30.5	29.3	29.9	28.7	30.5	28.7	30.5	29.9	29.9	29.3	30.5	29.3	29.3	29.3	28.7
29.9	28.7	28.7	30.5	29.3	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.9	29.9	29.3	30.5	29.9
30.5	30.5	29.3	28.7	30.5	29.3	29.3	29.9	29.9	28.7	30.5	29.3	30.5	28.7	30.5	28.7	29.9	30.5	29.3	30.5
28.7	29.9	30.5	29.3	29.9	30.5	29.3	30.5	29.3	30.5	29.3	29.9	29.9	29.9	29.3	29.9	28.7	29.3	28.7	29.3
29.3	28.7	29.3	29.9	28.7	29.9	29.9	29.3	29.9	29.9	29.3	30.5	28.7	30.5	28.7	30.5	29.9	29.3	30.5	29.3
30.5	29.9	29.3	29.3	29.9	28.7	29.9	29.3	30.5	28.7	29.9	28.7	29.9	29.3	30.5	29.3	30.5	29.9	29.9	30.5
28.7	30.5	30.5	29.3	30.5	29.9	28.7	30.5	29.3	29.9	29.9	28.7	30.5	29.3	29.9	29.3	28.7	30.5	28.7	29.3
28.7	28.7	29.3	30.5	29.3	30.5	29.9	29.3	29.3	30.5	28.7	30.5	28.7	30.5	28.7	30.5	29.9	28.7	29.9	28.7
30.5	29.3	28.7	29.9	29.3	28.7	30.5	29.3	30.5	29.3	29.9	29.9	29.3	29.3	29.9	29.3	30.5	29.9	30.5	30.5
29.9	30.5	29.9	28.7	30.5	29.3	28.7	30.5	29.3	29.3	30.5	28.7	30.5	28.7	30.5	29.3	29.9	30.5	29.3	30.5
28.7	29.3	30.5	29.9	29.3	30.5	29.3	29.9	29.3	30.5	28.7	29.9	29.3	30.5	29.3	30.5	29.3	29.3	29.3	28.7
29.9	28.7	28.7	30.5	29.3	29.3	30.5	28.7	29.9	29.3	29.3	30.5	29.3	29.9	29.3	29.9	30.5	29.3	30.5	29.9

30.5	30.5	29.3	28.7	29.9	29.3	29.3	29.9	29.9	28.7	30.5	28.7	30.5	28.7	30.5	28.7	29.9	30.5	29.9	30.5
29.3	29.9	30.5	29.3	29.9	30.5	29.3	30.5	28.7	30.5	29.3	29.3	30.5	29.9	29.3	29.9	28.7	29.3	28.7	29.3
29.3	28.7	29.3	30.5	28.7	30.5	30.5	29.3	29.3	29.9	29.3	30.5	29.3	30.5	28.7	30.5	29.9	28.7	29.9	29.3
30.5	29.9	29.3	29.3	29.9	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	30.5	28.7	30.5	29.9	30.5	30.5
29.3	30.5	30.5	29.3	30.5	29.9	28.7	30.5	29.3	29.9	29.9	29.9	30.5	29.3	29.9	29.9	29.3	29.9	28.7	29.3
29.3	29.3	29.9	30.5	29.3	29.9	29.9	29.3	29.3	30.5	28.7	29.9	29.3	30.5	28.7	30.5	29.3	28.7	29.9	28.7
30.5	29.3	28.7	29.9	29.3	28.7	30.5	28.7	30.5	28.7	29.9	29.9	29.3	29.9	29.3	29.3	30.5	29.3	30.5	30.5
29.9	30.5	29.9	28.7	30.5	29.3	29.3	30.5	29.9	29.3	30.5	28.7	30.5	29.3	30.5	29.3	29.3	30.5	29.3	30.5
28.7	29.3	29.9	29.9	29.3	30.5	29.3	29.9	29.3	30.5	28.7	29.9	29.9	30.5	28.7	30.5	28.7	29.3	29.3	28.7
29.9	29.3	29.3	30.5	29.3	29.3	30.5	28.7	30.5	29.9	29.3	29.9	28.7	30.5	28.7	29.3	30.5	29.3	30.5	29.9
30.5	30.5	29.9	29.3	30.5	28.7	29.3	29.9	29.9	28.7	30.5	28.7	30.5	29.3	30.5	28.7	30.5	30.5	29.9	30.5
28.7	29.9	30.5	29.3	29.9	30.5	29.3	30.5	28.7	30.5	29.3	29.3	29.9	29.9	29.3	29.9	28.7	29.9	28.7	29.3
29.3	28.7	29.3	30.5	28.7	29.9	30.5	29.3	29.3	30.5	29.3	30.5	28.7	30.5	28.7	29.9	29.9	28.7	30.5	29.3
30.5	29.9	29.3	29.3	29.9	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	30.5	29.3	29.9	29.9	30.5	30.5
29.9	30.5	30.5	29.3	30.5	29.9	28.7	30.5	29.3	29.9	29.9	28.7	30.5	29.3	29.9	29.3	29.3	30.5	28.7	29.3
28.7	28.7	29.9	30.5	29.3	30.5	29.9	29.3	29.3	30.5	29.3	30.5	29.3	30.5	28.7	30.5	29.3	28.7	29.9	28.7
30.5	29.3	29.3	29.9	29.3	28.7	30.5	29.3	29.9	29.3	29.9	29.9	29.3	29.9	29.9	29.3	30.5	29.3	30.5	30.5
29.9	30.5	29.9	28.7	30.5	29.3	29.3	30.5	29.9	29.3	30.5	28.7	30.5	28.7	30.5	29.3	29.9	30.5	29.3	29.9
28.7	29.3	30.5	29.9	29.9	30.5	29.3	29.9	28.7	30.5	29.3	29.9	29.9	29.9	29.3	30.5	28.7	29.3	29.3	28.7
29.9	29.3	28.7	30.5	28.7	29.3	30.5	28.7	29.9	29.9	29.3	30.5	29.3	29.9	29.3	29.9	30.5	29.3	30.5	29.9
30.5	30.5	29.3	28.7	30.5	29.3	29.3	29.9	30.5	28.7	30.5	29.3	30.5	28.7	30.5	28.7	29.9	30.5	29.9	30.5
29.3	29.9	30.5	29.3	30.5	30.5	29.9	30.5	28.7	29.9	29.3	29.3	29.9	29.3	29.9	29.9	28.7	29.9	29.3	29.3
29.3	28.7	29.3	30.5	29.3	29.9	30.5	29.3	29.9	29.9	28.7	30.5	28.7	30.5	28.7	29.9	29.9	28.7	29.9	29.3
30.5	29.9	29.3	29.3	29.9	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	30.5	29.3	30.5	29.9	29.9	30.5
29.3	30.5	30.5	29.3	30.5	29.9	28.7	30.5	29.3	29.9	29.9	28.7	30.5	29.3	30.5	29.3	29.3	29.9	28.7	29.9
28.7	29.3	29.9	30.5	29.3	29.9	29.9	29.9	29.3	30.5	28.7	30.5	29.3	30.5	29.3	30.5	29.3	28.7	29.3	28.7
29.9	29.3	28.7	29.9	29.3	29.3	30.5	29.3	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.3	30.5	29.3	30.5	30.5
29.9	30.5	29.9	28.7	30.5	29.3	28.7	29.9	29.3	29.3	29.9	28.7	30.5	28.7	30.5	28.7	29.3	30.5	29.3	29.9
28.7	29.3	29.9	29.9	29.3	30.5	29.3	29.9	28.7	30.5	29.3	29.9	29.9	29.3	29.3	30.5	28.7	29.3	29.3	28.7
29.9	28.7	28.7	30.5	28.7	29.3	30.5	28.7	29.9	29.9	29.3	30.5	28.7	29.9	29.3	29.9	29.9	29.3	30.5	29.9
30.5	30.5	29.9	29.3	30.5	29.3	29.3	29.9	30.5	28.7	30.5	29.3	29.9	29.3	30.5	28.7	29.9	30.5	29.9	30.5
29.3	29.9	30.5	29.3	29.9	30.5	29.3	30.5	29.3	29.9	29.3	29.3	29.9	29.3	29.3	29.9	28.7	29.9	28.7	29.3
29.3	28.7	29.3	30.5	28.7	29.9	30.5	29.3	29.3	30.5	29.3	30.5	29.3	30.5	28.7	30.5	29.9	29.3	29.9	29.3
30.5	29.9	28.7	29.3	29.9	28.7	29.9	29.3	30.5	29.3	30.5	29.3	29.9	29.3	29.9	29.3	30.5	29.9	29.9	30.5
29.3	30.5	30.5	29.3	30.5	29.9	28.7	30.5	29.3	29.9	30.5	29.3	30.5	29.3	30.5	29.3	29.3	29.9	28.7	29.9
28.7	28.7	29.3	30.5	29.3	30.5	29.9	29.9	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.3	29.3	29.3	29.3
30.5	29.3	28.7	29.9	29.3	29.3	29.9	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.3	30.5	29.9	30.5	30.5
29.9	30.5	30.5	28.7	30.5	29.3	28.7	29.9	29.9	29.3	29.9	28.7	30.5	28.7	30.5	28.7	29.3	30.5	29.3	29.9
28.7	29.3	29.9	29.9	29.9	30.5	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.9	29.3	30.5	28.7	29.3	29.3	28.7
29.9	28.7	28.7	30.5	29.3	29.3	30.5	29.3	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.9	30.5	29.3	30.5	29.9
30.5	30.5	29.3	28.7	29.9	29.3	29.3	29.9	30.5	28.7	30.5	28.7	29.9	28.7	30.5	28.7	29.9	30.5	29.9	30.5
29.3	29.9	30.5	29.3	30.5	30.5	28.7	30.5	28.7	29.9	29.3	29.3	30.5	29.9	29.9	29.9	28.7	29.9	28.7	29.3
29.3	28.7	29.3	30.5	28.7	29.9	30.5	29.3	29.3	29.9	28.7	30.5	29.3	30.5	28.7	30.5	29.3	28.7	29.9	29.3
30.5	29.9	29.3	29.3	29.9	28.7	29.9	29.3	30.5	28.7	29.9	29.3	29.3	29.3	29.9	29.3	30.5	29.9	30.5	30.5
29.3	30.5	30.5	29.3	30.5	29.9	28.7	30.5	29.3	29.3	29.9	29.3	30.5	29.3	30.5	29.3	29.3	30.5	28.7	29.9

28.7	29.3	29.9	30.5	29.3	30.5	29.9	29.9	28.7	30.5	28.7	29.9	29.3	30.5	29.3	30.5	29.3	28.7	29.3	28.7
30.5	29.3	28.7	29.9	29.3	29.3	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.3	30.5	29.3	30.5	30.5
29.9	30.5	29.9	28.7	30.5	29.3	29.3	30.5	29.9	29.3	30.5	28.7	30.5	28.7	30.5	28.7	29.9	30.5	29.3	30.5
28.7	29.3	29.9	29.9	29.3	30.5	29.9	30.5	28.7	30.5	29.3	29.9	29.9	30.5	29.3	30.5	28.7	29.3	28.7	28.7
29.9	29.3	29.3	30.5	29.3	29.3	30.5	28.7	30.5	29.9	29.3	30.5	28.7	30.5	29.3	29.9	30.5	29.3	30.5	29.3
30.5	29.9	29.3	29.3	30.5	29.3	29.9	29.9	30.5	28.7	30.5	29.3	30.5	29.3	30.5	28.7	29.9	30.5	29.9	30.5
29.3	29.9	30.5	29.3	30.5	30.5	28.7	30.5	29.3	29.9	29.3	29.3	30.5	29.3	29.9	29.9	28.7	29.9	28.7	29.3
29.3	28.7	29.3	30.5	28.7	29.9	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.9	28.7	29.9	29.3
30.5	29.9	29.3	29.3	29.3	28.7	29.9	29.3	30.5	29.3	30.5	29.9	29.3	29.3	29.9	28.7	30.5	29.9	30.5	30.5
29.9	30.5	30.5	28.7	30.5	29.9	28.7	30.5	29.3	29.3	29.9	28.7	30.5	28.7	30.5	29.3	29.3	30.5	29.3	29.9
28.7	28.7	29.9	30.5	29.3	30.5	29.9	29.9	29.3	30.5	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.3	29.3	28.7
29.9	29.3	28.7	29.9	29.3	28.7	30.5	28.7	30.5	29.3	29.9	30.5	29.3	29.9	29.3	29.3	30.5	29.3	30.5	29.9
29.9	30.5	29.9	28.7	30.5	29.3	29.3	30.5	29.9	29.3	30.5	28.7	30.5	28.7	30.5	29.3	29.3	30.5	29.3	30.5
28.7	29.3	30.5	29.3	29.9	30.5	29.3	29.9	28.7	30.5	29.3	29.9	29.9	29.9	29.3	30.5	28.7	29.3	29.3	29.3
29.3	28.7	28.7	30.5	28.7	29.3	30.5	28.7	29.9	29.9	29.3	30.5	28.7	30.5	28.7	30.5	30.5	29.3	30.5	29.9
30.5	29.9	29.3	29.3	29.9	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	29.9	29.3	29.9	30.5	29.9	30.5
29.3	29.9	30.5	29.3	29.9	30.5	28.7	30.5	29.3	29.9	29.3	29.3	30.5	29.3	29.9	29.9	28.7	29.9	28.7	29.3
29.3	28.7	29.3	30.5	28.7	29.9	30.5	29.3	29.3	30.5	29.3	30.5	29.3	30.5	28.7	30.5	29.9	28.7	29.9	28.7
30.5	29.9	29.3	29.3	29.9	28.7	29.9	28.7	30.5	29.3	30.5	29.9	29.3	29.3	29.9	29.3	30.5	29.9	30.5	30.5
29.9	30.5	30.5	28.7	30.5	29.9	28.7	30.5	29.3	29.3	29.9	28.7	30.5	29.3	30.5	29.3	29.3	30.5	28.7	29.9
29.3	28.7	29.9	29.9	29.3	30.5	29.9	29.9	28.7	30.5	28.7	30.5	29.3	30.5	29.3	30.5	28.7	29.3	29.3	28.7
30.5	29.3	28.7	29.9	29.3	29.3	30.5	28.7	29.9	29.3	29.3	30.5	29.3	29.9	29.3	29.3	30.5	29.3	30.5	29.9
29.9	30.5	30.5	28.7	30.5	29.3	29.3	29.9	29.9	28.7	30.5	28.7	30.5	28.7	30.5	28.7	29.9	30.5	29.3	30.5
28.7	29.3	29.9	29.9	29.3	30.5	29.3	30.5	29.3	30.5	29.3	29.9	29.9	29.9	29.3	30.5	29.3	29.3	28.7	28.7
29.9	28.7	29.3	30.5	29.3	29.3	30.5	28.7	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.9	30.5	29.3	30.5	29.3
30.5	29.9	29.3	29.3	29.9	28.7	29.3	29.3	30.5	28.7	30.5	29.3	29.9	29.3	29.9	28.7	30.5	30.5	29.9	31.2
29.3	29.9	30.5	28.7	29.9	30.5	28.7	29.9	28.7	29.9	29.9	29.3	30.5	29.3	29.9	29.9	28.7	29.9	28.7	29.3
29.3	28.7	29.3	30.5	28.7	29.9	29.9	29.3	29.3	30.5	28.7	30.5	28.7	30.5	28.7	30.5	29.9	28.7	29.9	29.3
30.5	29.9	29.3	29.9	29.9	28.7	29.9	29.3	30.5	29.3	30.5	29.9	29.3	29.3	29.9	29.3	30.5	29.9	30.5	30.5
29.9	30.5	30.5	28.7	30.5	29.9	28.7	30.5	29.3	29.3	30.5	28.7	30.5	29.3	30.5	29.3	29.3	29.9	29.3	29.9
29.3	29.3	29.9	30.5	29.3	30.5	29.9	29.9	28.7	30.5	28.7	29.9	29.3	30.5	29.3	30.5	29.3	29.3	29.3	28.7
29.9	29.3	28.7	29.9	29.3	28.7	30.5	28.7	30.5	29.3	29.3	30.5	29.3	30.5	29.3	29.9	30.5	29.3	29.9	29.9
30.5	30.5	29.9	28.7	30.5	29.3	29.3	29.9	29.9	28.7	30.5	28.7	29.9	29.3	30.5	28.7	29.9	30.5	29.3	29.9
28.7	29.3	30.5	29.9	29.9	30.5	29.3	30.5	28.7	30.5	29.3	29.3	29.9	29.9	29.3	29.9	28.7	29.9	28.7	29.3
29.3	29.3	29.3	30.5	29.3	29.3	30.5	28.7	29.3	30.5	29.3	29.9	28.1	30.5	28.7	30.5	30.5	29.3	30.5	29.3
30.5	29.9	29.3	29.3	29.9	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	29.9	28.7	29.9	30.5	29.9	30.5
29.3	29.9	30.5	29.3	29.9	30.5	28.7	30.5	28.7	29.9	29.9	29.3	30.5	29.3	29.9	29.9	28.7	29.9	29.3	29.3
29.3	28.7	29.3	30.5	28.7	29.9	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.9	28.7	29.9	28.7
30.5	29.9	29.3	29.9	29.9	28.7	30.5	29.3	30.5	29.3	30.5	29.9	29.3	29.9	29.9	29.3	30.5	29.9	30.5	30.5
29.9	30.5	30.5	28.7	30.5	29.9	28.7	30.5	29.3	29.3	30.5	28.7	30.5	29.3	30.5	29.3	29.3	30.5	29.3	29.9
28.7	29.3	29.9	29.9	28.7	30.5	29.9	29.9	28.7	30.5	28.7	29.9	29.3	30.5	29.3	30.5	29.3	28.7	29.3	28.7
29.9	29.3	29.3	29.9	29.3	29.3	30.5	28.7	30.5	29.9	29.9	30.5	29.3	29.9	29.3	29.9	30.5	29.3	30.5	29.9
29.9	30.5	29.9	28.7	30.5	29.3	29.3	29.9	29.9	28.7	30.5	28.7	30.5	29.3	30.5	28.7	29.9	30.5	29.9	29.9
28.7	29.3	30.5	29.3	29.9	30.5	29.3	30.5	28.7	30.5	29.3	29.3	29.9	29.9	29.9	29.9	28.7	29.3	29.3	29.3
29.9	28.7	29.3	30.5	28.7	29.3	30.5	29.3	29.9	29.9	28.7	30.5	28.7	30.5	29.3	30.5	30.5	29.3	29.9	29.3

30.5	30.5	29.3	29.3	29.9	28.7	29.3	29.3	30.5	29.3	30.5	29.3	29.9	29.3	29.9	28.7	29.9	30.5	29.9	30.5
29.3	30.5	30.5	29.3	29.9	30.5	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.3	29.9	29.9	28.7	29.9	28.7	29.3
29.3	28.7	29.3	30.5	28.7	29.9	29.9	29.9	29.3	30.5	29.3	30.5	28.7	30.5	28.7	30.5	29.9	28.7	29.9	28.7
30.5	29.9	28.7	29.9	29.3	28.7	29.9	28.7	30.5	29.3	29.9	29.9	29.3	29.3	29.9	29.3	30.5	29.9	30.5	30.5
29.9	30.5	30.5	28.7	30.5	29.9	29.3	30.5	29.9	29.3	29.9	28.7	30.5	28.7	30.5	29.3	29.3	30.5	28.7	29.9
28.7	29.3	29.9	30.5	29.3	30.5	29.3	29.9	28.7	30.5	28.7	30.5	29.3	30.5	29.3	30.5	29.3	28.7	29.3	28.7
29.9	29.3	28.7	30.5	29.3	28.7	30.5	28.7	30.5	29.9	29.3	30.5	28.7	29.9	29.3	29.9	30.5	29.3	30.5	29.9
29.9	30.5	29.9	29.3	30.5	29.3	29.3	29.3	29.9	28.7	30.5	28.7	30.5	28.7	30.5	28.7	29.9	30.5	29.3	30.5
28.7	29.9	30.5	29.3	29.9	30.5	29.3	30.5	28.7	29.9	29.3	29.3	29.9	29.9	29.3	29.9	29.3	29.3	28.7	29.3
29.3	29.3	29.3	30.5	28.7	29.9	30.5	29.3	29.3	29.9	29.3	30.5	28.7	30.5	28.7	29.9	29.9	28.7	30.5	29.3
30.5	29.9	29.3	29.3	29.9	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	29.9	28.7	30.5	30.5	29.9	30.5
29.3	29.9	30.5	29.3	30.5	29.9	28.7	30.5	29.3	29.9	29.9	29.3	30.5	29.3	29.9	29.3	28.7	29.9	28.7	29.3
29.3	28.7	29.3	30.5	28.7	30.5	29.9	29.3	29.3	30.5	28.7	30.5	29.3	30.5	28.7	30.5	29.3	29.3	29.9	29.3
30.5	29.9	29.3	29.9	29.9	28.7	30.5	28.7	30.5	29.3	30.5	29.9	29.3	29.3	29.9	29.3	30.5	29.9	30.5	30.5
29.9	30.5	30.5	29.3	30.5	29.9	28.7	29.9	29.3	28.7	30.5	29.3	30.5	28.7	30.5	29.3	28.7	30.5	29.3	29.9
28.7	29.3	29.9	29.9	29.3	30.5	29.3	29.9	28.7	30.5	28.7	29.9	29.3	29.9	29.3	30.5	29.3	28.7	29.3	28.7
29.9	29.3	28.7	30.5	29.3	29.3	30.5	28.7	30.5	29.9	29.3	29.9	29.3	29.9	29.3	29.9	30.5	29.3	30.5	29.9
30.5	30.5	29.9	29.3	30.5	29.3	29.3	29.9	30.5	29.3	30.5	28.7	30.5	28.7	30.5	28.7	29.9	30.5	29.9	30.5
28.7	29.3	30.5	29.3	29.9	30.5	29.3	30.5	28.7	30.5	29.3	29.3	29.9	29.9	29.9	29.9	28.7	29.9	28.7	29.3
29.3	28.7	28.7	30.5	28.7	29.3	29.9	28.7	29.3	30.5	29.3	30.5	28.7	30.5	28.7	30.5	29.9	28.7	29.9	29.3
30.5	29.9	29.3	29.3	29.9	29.3	29.9	29.3	30.5	28.7	30.5	29.9	29.3	29.3	29.9	28.7	29.9	30.5	29.9	30.5
29.3	29.9	30.5	29.3	30.5	30.5	28.7	30.5	29.3	29.3	29.9	29.3	30.5	29.3	29.9	29.9	29.3	29.9	28.7	29.3
29.3	28.7	29.3	30.5	29.3	29.9	29.9	29.3	29.3	30.5	28.7	29.9	29.3	30.5	28.7	30.5	29.9	28.7	29.3	28.7
29.9	29.9	28.7	29.9	29.3	28.7	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.3	30.5	30.5	30.5	30.5
29.9	30.5	30.5	28.7	30.5	29.9	29.3	29.9	29.9	28.7	30.5	28.7	30.5	29.3	30.5	29.3	29.3	30.5	29.3	29.9
28.7	29.3	29.9	29.9	29.3	30.5	29.3	29.9	28.7	30.5	28.7	29.9	29.9	29.9	29.3	30.5	28.7	29.3	29.3	28.7
29.9	29.3	28.7	30.5	29.3	29.3	30.5	28.7	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.9	30.5	29.3	30.5	29.9
29.9	30.5	29.9	28.7	30.5	29.3	29.3	29.9	30.5	28.7	30.5	29.3	30.5	28.7	30.5	28.7	29.9	30.5	29.9	30.5
28.7	29.9	30.5	29.3	29.9	30.5	29.3	30.5	29.3	29.9	29.3	29.3	29.9	29.3	29.9	29.9	28.7	29.3	28.7	29.3
29.3	29.3	28.7	30.5	28.7	29.3	30.5	29.3	29.3	30.5	28.7	30.5	28.7	30.5	28.7	29.9	29.9	28.7	30.5	29.3
30.5	30.5	29.3	29.3	29.9	28.7	29.9	29.3	30.5	28.7	30.5	29.3	29.3	28.7	29.9	29.3	29.9	30.5	30.5	30.5
29.3	29.9	30.5	29.3	30.5	30.5	28.7	30.5	29.3	29.3	29.9	29.3	30.5	29.3	30.5	29.3	29.3	29.9	28.7	29.9
29.3	28.7	29.3	30.5	28.7	29.9	29.9	29.9	29.3	30.5	28.7	30.5	28.7	30.5	28.7	30.5	29.3	28.7	29.3	29.3
29.9	29.9	29.3	29.9	29.3	28.7	30.5	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.3	30.5	29.9	30.5	30.5
29.9	30.5	30.5	28.7	30.5	29.9	29.3	29.9	29.9	28.7	30.5	28.7	30.5	28.7	30.5	29.3	29.3	30.5	28.7	29.9
28.7	29.3	29.9	29.9	29.3	30.5	29.3	29.9	29.3	30.5	29.3	29.9	29.9	29.9	29.3	30.5	29.3	29.3	29.3	29.3
29.9	29.3	28.7	30.5	28.7	29.3	30.5	28.7	29.9	29.9	29.3	30.5	29.3	29.9	29.3	29.9	30.5	29.3	30.5	29.9
29.9	30.5	29.9	29.3	30.5	29.3	29.3	29.9	30.5	28.7	30.5	29.3	30.5	29.3	30.5	28.7	29.9	30.5	29.9	30.5
29.3	29.9	29.9	29.3	29.9	30.5	29.3	30.5	29.3	29.9	29.3	29.3	30.5	29.9	29.9	29.9	28.7	29.3	28.7	29.3
29.3	28.7	29.3	30.5	28.7	29.9	29.9	29.3	29.3	29.9	29.3	30.5	28.7	30.5	28.7	30.5	29.9	28.7	29.9	29.3
30.5	30.5	29.3	29.9	29.9	29.3	29.9	29.3	30.5	28.7	30.5	29.3	29.9	29.3	30.5	29.3	30.5	29.9	29.9	30.5
29.3	29.9	30.5	29.3	30.5	30.5	28.7	30.5	29.3	29.3	29.9	29.3	30.5	29.3	30.5	29.9	28.7	29.9	28.7	29.9
28.7	28.7	29.3	30.5	29.3	29.9	29.9	29.9	29.3	30.5	29.3	30.5	29.3	30.5	29.3	30.5	29.9	28.7	29.3	29.3
30.5	29.9	28.7	29.9	29.3	28.7	29.9	28.7	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.3	30.5	29.9	30.5	30.5
29.9	30.5	29.9	28.7	30.5	29.9	28.7	29.9	29.9	28.7	30.5	28.7	30.5	28.7	30.5	29.3	29.3	30.5	29.3	29.9

28.7	29.3	29.9	29.9	29.3	30.5	29.3	30.5	28.7	29.9	29.3	29.9	29.9	29.9	29.3	30.5	29.3	29.3	29.3	28.7
29.9	29.3	28.7	30.5	28.7	29.3	30.5	28.7	29.9	29.9	29.3	30.5	28.7	30.5	29.3	29.9	30.5	29.3	30.5	29.9
29.9	30.5	29.9	28.7	30.5	29.3	29.3	29.3	30.5	28.7	30.5	29.3	29.9	28.7	30.5	28.7	29.9	30.5	29.9	29.9
28.7	29.9	30.5	29.3	29.9	30.5	29.3	30.5	29.3	29.9	29.3	29.3	30.5	29.3	29.9	29.9	29.3	29.9	29.3	29.3
29.9	28.7	28.7	30.5	28.7	29.9	29.9	29.3	29.3	30.5	28.7	30.5	28.7	30.5	28.7	30.5	29.9	29.9	29.9	29.3

Appendix C

Chemical and Thermophysical Properties of H13 Steel and Water

This appendix contains selected thermophysical properties of H13 steel and pure water. C.1 lists thermophysical property values for steel H13. Data source is the database of Magwasoft Technologies Inc. C.2 lists the chemical composition of H13, a chromium-based tool steel for high temperature applications including dies. C.3 lists thermophysical property values for pure water. Data source is the Chemical Hazards Response Information System (CHRIS).

C.1 Selected Thermophysical Property Values of Steel H13

274	25	7830	426.054
373	26	7806	485.524
473	27	7776	532.022
573	27.4	7747	565.122
673	27.3	7711	604.85
773	26.8	7681	665.538
873	26.4	7644	768.707
973	26.2	7621	1400
1070	26.3	7597	890.604
1170	26.8	7578	600.053

C.2 Composition of H13 Chromium-Based Tool Steel

Carbon	0.35
Chromium	5.00
Vanadium	1.00
Molybdenum	1.50

C.3 Selected Thermophysical Property Values of 100% Water

273	0.567	1000	0.00177	4220
278	0.574	1000	0.00154	4200
283	0.582	1000	0.00130	4190
285	0.591	999	0.00112	4190
290	0.599	998	0.00097	4180
295	0.607	996	0.00086	4180
300	0.616	995	0.00076	4180
305	0.624	993	0.00068	4180
310	0.633	991	0.00062	4180
315	0.641	988	0.00056	4180

Appendix D

PC Host Software Code

This appendix contains PC host software code. The software program is responsible for acquiring data at a required sampling rate, and displaying that data on the screen in both graphic and value formats. It also outputs a control signal to the data acquisition board to control the pump according to the user input.

D.1 Project1.cpp

```
//---------------------------------------------------------------------------
#include <vcl.h>
#pragma hdrstop
USERES("Project1.res");
USEFORM("Unit1.cpp", Form1);
USELIB("cbw32bc.lib");
USEFORM("About.cpp", Form3);
USEFORM("PumpSpeed.cpp", Form2);
//---------------------------------------------------------------------------
WINAPI WinMain(HINSTANCE, HINSTANCE, LPSTR, int)
{
   try
   {
      Application->Initialize();
      Application->CreateForm(__classid(TForm1), &Form1);
      Application->CreateForm(__classid(TForm3), &Form3);
      Application->CreateForm(__classid(TForm2), &Form2);
      Application->Run();
   }
   catch (Exception &exception)
   {
      Application->ShowException(&exception);
   }
   return 0;
}
//---------------------------------------------------------------------------
```

D.2 Unit1.cpp

```
//---------------------------------------------------------------------------
#include <vcl.h>
#pragma hdrstop

#include "Unit1.h"
#include "PumpSpeed.h"
#include "About.h"
#include "cbw.h"
/*GLOBAL VARIABLES*/
unsigned short BufferForT1[2*DISPLAYLENGTH]; //CHANNEL ONE:CIRCULAR BUFFER
unsigned short BufferForT2[2*DISPLAYLENGTH];//CHANNEL TWO:CIRCULAR BUFFER
unsigned short BufferForT3[2*DISPLAYLENGTH]; //CHANNEL THREE:CIRCULAR BUFFER
unsigned short BufferForF[2*DISPLAYLENGTH]; //CIRCULAR BUFFER
static unsigned short *indexT1=BufferForT1;//CHANNEL ONE:INDEX POINTER
static unsigned short *indexT2=BufferForT2;//CHANNEL TOW:INDEX POINTER
static unsigned short *indexT3=BufferForT3;//CHANNEL THREE:INDEX POINTER
static unsigned short *indexF=BufferForF;//INDEX POINTER
unsigned short BK=DISPLAYLENGTH; //LENGTH OF THE CIRCULAR BUFFER
int SAMPLERATE=100;//SAMPLING RATE IS 100MS
const float scalarT=0.61099796;   //600 corresponding to 982
 //thermocouple amplifier output is 2.4V(982) when temperature is 600 Celsius
const float scalarF=0.10853344;   //500 corresponding to 4095,55.55556 to 0
```

```
const float startpoint=55.55556;
unsigned int BITVALUE;
unsigned int BITNUM;
static unsigned short AutoStart=0;
static unsigned short AutoStop=0;

//---------------------------------------------------------------------
#pragma package(smart_init)
#pragma resource "*.dfm"

TForm1 *Form1;
//---------------------------------------------------------------------
__fastcall TForm1::TForm1(TComponent* Owner)
   : TForm(Owner)
{  /* confige digital output bit*/
  cbDConfigPort(BOARD_NUM,FIRSTPORTA,DIGITALOUT);
 /* Set library's error handling */
  cbErrHandling (PRINTALL, STOPALL);

   Label22->Caption=TimeToStr(Time());
   Label23->Caption=DateToStr(Date());
   Label24->Caption="0.1s";
   Timer2->Enabled=true;
   PumpFlag=0;
   ComboBox1->Enabled=false; //BY DEFAULT, IT MANUAL CONTROL MODE
   ComboBox2->Enabled=false;
   CheckBox1->Checked=false;

   for(int i=0;i<DISPLAYLENGTH;i++)
     {
      BufferForT1[i]=0;
      BufferForT2[i]=0;
      BufferForT3[i]=0;
      BufferForF[i]=0;  }
   Timer1->Interval=SAMPLERATE;

}
//--UPDATE THE TIME AND DATE ON TEH FORM -----------
void __fastcall TForm1::Timer2Timer(TObject *Sender)
{
   Label22->Caption=TimeToStr(Time());
   Label23->Caption=DateToStr(Date());
}
//-----DRAW BLACK BACKGROUND ON THE PAINTBOX1-----------
void __fastcall TForm1::Paint1(TObject *Sender)
{
   int Width=PaintBox1->Width;
   int Height=PaintBox1->Height;
   TRect newRect=Rect(0,0,Width,Height);
   PaintBox1->Canvas->Brush->Color=clBlack;
   PaintBox1->Canvas->FillRect(newRect);
   drawlines();
}
//-----DRAW BALCK BACKGROUND ON THE PAINTBOX2 ---------
void __fastcall TForm1::Paint2(TObject *Sender)
{
```

```
    int Width=PaintBox2->Width;
    int Height=PaintBox2->Height;
    TRect newRect=Rect(0,0,Width,Height);
    PaintBox2->Canvas->Brush->Color=clBlack;
    PaintBox2->Canvas->FillRect(newRect);
    drawlines();

}
//-------DRAW COORDINATE LINES ----------------------
void TForm1::drawlines(void)
{
   int Width1=PaintBox1->Width;
   int Height1=PaintBox1->Height;
   int Width2=PaintBox2->Width;
   int Height2=PaintBox2->Height;
   int i;
   PaintBox1->Canvas->Pen->Color=clTeal;
   PaintBox2->Canvas->Pen->Color=clTeal;
   for(i=1;i<LINENUMX;i++)
   {
     PaintBox1->Canvas->MoveTo(i*Width1/LINENUMX,0);
     PaintBox2->Canvas->MoveTo(i*Width1/LINENUMX,0);
     PaintBox1->Canvas->LineTo(i*Width2/LINENUMX,Height);
     PaintBox2->Canvas->LineTo(i*Width2/LINENUMX,Height);
   }
   for(i=1;i<LINENUMY;i++)
   {
      PaintBox1->Canvas->MoveTo(0,i*Height1/LINENUMY);
      PaintBox2->Canvas->MoveTo(0,i*Height2/LINENUMF);
      PaintBox1->Canvas->LineTo(Width,i*Height1/LINENUMY);
      PaintBox2->Canvas->LineTo(Width,i*Height2/LINENUMF);
   }
}
//---------PREPARE DATA FOR DISPLAY ---------------
void TForm1::prepare_data_for_display(TPaintBox *PP,int fly)
{
   int Width=PP->Width;
   int Height=PP->Height;
   unsigned short *ptrT1,*ptrF,*ptrT2,*ptrT3;
   ptrT1=indexT1;
   ptrT2=indexT2;
   ptrT3=indexT3;
   ptrF=indexF;
   if(fly==0)    //TEMPERATURE PAINTBOX
   {
      for(int i=0;i<DISPLAYLENGTH;i++)
      {  //CHANNEL ONE
         T1Points[i]=Point((long)i*Width/DISPLAYLENGTH,
                        (long)(Height-((*ptrT1++)-MINT)*Height/(MAXT-MINT)));
         if((ptrT1-BufferForT1)>=BK)  //CIRCULAR ADDRESSING
            ptrT1=BufferForT1;
         //CHANNEL TWO
         T2Points[i]=Point((long)i*Width/DISPLAYLENGTH,
                        (long)(Height-((*ptrT2++)-MINT)*Height/(MAXT-MINT)));
         if((ptrT2-BufferForT2)>=BK)  //CIRCULAR ADDRESSING
            ptrT2=BufferForT2;
```

```
        //CHANNEL THREE
        T3Points[i]=Point((long)i*Width/DISPLAYLENGTH,
                        (long)(Height-((*ptrT3++)-MINT)*Height/(MAXT-MINT)));
        if((ptrT3-BufferForT3)>=BK)  //CIRCULAR ADDRESSING
          ptrT3=BufferForT3;

      }
    }
    else
    {
      for(int i=0;i<DISPLAYLENGTH;i++)
      {
        FPoints[i]=Point((long)i*Width/DISPLAYLENGTH,
                    (long)(Height-((*ptrF++)-MINF)*Height/(MAXF-MINF)));
        if((ptrF-BufferForF)>=BK) //CIRCULAR ADDRESSING
          ptrF=BufferForF;
      }
    }
}

//----------DRAW THE NEW DATA ON SCREEN--------------
void TForm1::display_data(TPaintBox *PP,int fly)
{  if(fly==0) //FLY=0 MEANS TEMPERATURE PAINTBOX
    {//CHANNEL ONE
     PP->Canvas->Pen->Color=clRed;
     PP->Canvas->Polyline(EXISTINGARRAY(T1Points));
     //CHANNEL TWO
     PP->Canvas->Pen->Color=clYellow;
     PP->Canvas->Polyline(EXISTINGARRAY(T2Points));
     //CHANNEL THREE
     PP->Canvas->Pen->Color=clAqua;
     PP->Canvas->Polyline(EXISTINGARRAY(T3Points));
     }
   else    // FLOWRATE PAINTBOX
     {
     PP->Canvas->Pen->Color=clBlue;
     PP->Canvas->Polyline(EXISTINGARRAY(FPoints));
     }
}

//-- SAMPLING DATA AT A FIXED INTERVAL AND DISPLAY THEM-----
void __fastcall TForm1::Timer1Timer(TObject *Sender)
{
    //READ DATA FROM DATA ACQUISITIOIN BOARD
    //ERASE THE OLD CURVE
    //DRAW NEW CURVE
    read_data();

    PaintBox1->Canvas->Pen->Color=clBlack;
    PaintBox1->Canvas->Polyline(EXISTINGARRAY(T1Points));
    PaintBox1->Canvas->Polyline(EXISTINGARRAY(T2Points));
    PaintBox1->Canvas->Polyline(EXISTINGARRAY(T3Points));
    PaintBox2->Canvas->Pen->Color=clBlack;
    PaintBox2->Canvas->Polyline(EXISTINGARRAY(FPoints));
    drawlines();
```

```
    prepare_data_for_display(PaintBox1,0);
    prepare_data_for_display(PaintBox2,1);
    display_data(PaintBox1,0);
    display_data(PaintBox2,1);
    converttostr();

}

//------READ DATA FROM DATA ACQUISITION BOARD ---------
void TForm1::read_data(void)
{
    unsigned short DataT1,DataF,DataT2,DataT3;
    /*READ DATA FROM DATA ACQUISITION BOARD ONE DATA EACH TIME*/
    cbAIn(BOARD_NUM, 0, ADRANGE, &DataT1);

    // CHANNEL TWO AND THREE
    cbAIn(BOARD_NUM, 2, ADRANGE, &DataT2);
    cbAIn(BOARD_NUM, 3, ADRANGE, &DataT3);

    cbAIn(BOARD_NUM,1,ADRANGE,&DataF);
    /*REPLACE THE OLDEST DATA WITH NEWEST DATA*/
    /*INDEX ALWAYS POINTS TO THE OLDEST DATA*/
    *indexT1++= (unsigned short)((float)DataT1*scalarT);
    *indexT2++= (unsigned short)((float)DataT2*scalarT);
    *indexT3++= (unsigned short)((float)DataT3*scalarT);

    *indexF++= (unsigned short)((float)DataF*scalarF+startpoint);
    if((indexT1-BufferForT1)>=BK) //CIRCULAR ADDRESSING
       indexT1=BufferForT1;
    /*CHANNEL TWO AND THREE*/
    if((indexT2-BufferForT2)>=BK) //CIRCULAR ADDRESSING
       indexT2=BufferForT2;
    if((indexT3-BufferForT3)>=BK) //CIRCULAR ADDRESSING
       indexT3=BufferForT3;

    if((indexF-BufferForF)>=BK)
       indexF=BufferForF;

    //PUMP RUNS AUTOMATICALLY WHEN AUTOMATIC MODE IS SELCEDTED
    if(CheckBox1->Checked==true)
      {
       if(ComboBox1->Enabled==false)
          ComboBox1->Enabled=true;
       if(ComboBox2->Enabled==false)
          ComboBox2->Enabled=true;

       AutoStart=(unsigned short)StrToFloat(ComboBox1->Text);
       AutoStop=(unsigned short)StrToFloat(ComboBox2->Text);
       if(AutoStart>AutoStop)
       { if(SpeedStartPump->Enabled==true)
            SpeedStartPump->Enabled=false;
         if(SpeedStopPump->Enabled==true)
            SpeedStopPump->Enabled=false;
         if(StartPump->Enabled==true)
            StartPump->Enabled=false;
         if(StopPump->Enabled==true)
```

```
          StopPump->Enabled=false;
        if(((DataT1*scalarT)>=AutoStart)&&(PumpFlag==0))
          AutoStartPump();
        if(((DataT1*scalarT)<=AutoStop)&&(PumpFlag==1))
          AutoStopPump();
      }
      else
        Close();
    }
  else if(CheckBox1->Checked==false)
    {  if(ComboBox1->Enabled==true)
          ComboBox1->Enabled=false;
       if(ComboBox2->Enabled==true)
          ComboBox2->Enabled=false;
       if(SpeedStartPump->Enabled==false)
          SpeedStartPump->Enabled=true;
       if(SpeedStopPump->Enabled==false)
          SpeedStopPump->Enabled=true;
       if(StartPump->Enabled==false)
          StartPump->Enabled=true;
       if(StopPump->Enabled==false)
          StopPump->Enabled=true;
    }
}

//------ START TO DISPLAY DATA -------------------

void __fastcall TForm1::StartDisplayClick(TObject *Sender)
{
  Timer1->Enabled=true;
}

//------PAUSE DISPLAYING DATA ----------------------
void __fastcall TForm1::PauseDisplayClick(TObject *Sender)
{
  Timer1->Enabled=false;
}
//--------EXIT THE MAIN PROGRAM ------------------

void __fastcall TForm1::FileExitClick(TObject *Sender)
{
   Close();
}

//----DISPLAY TEMPERATURE AND FLOW RATE VALUES -------------------------
void TForm1::converttostr(void)
{  unsigned short *ptrT1,*ptrF,*ptrT2,*ptrT3;
   if((indexT1-1)<BufferForT1)    /*CIRCULAR ADDRESSING*/
      ptrT1=(BufferForT1-1+BK); /*NEWEST DATA*/
   else
      ptrT1=indexT1-1;          /*NEWEST DATA*/

   // CHANNEL TWO AND THREE
   if((indexT2-1)<BufferForT2)
      ptrT2=(BufferForT2-1+BK);
   else
```

```
    ptrT2=indexT2-1;

  if((indexT3-1)<BufferForT3)
    ptrT3=(BufferForT3-1+BK);
  else
    ptrT3=indexT3-1;

  if((indexF-1)<BufferForF) /*CIRCULAR ADDRESSING*/
    ptrF=(BufferForF-1+BK);  /*NEWEST DATA*/
  else
    ptrF=indexF-1; /*NEWEST DATA*/
  char str[4];
  sprintf(str,"%d",*ptrT1);
  Label25->Caption=str;
  // CHANNEL TWO AND THREE
  sprintf(str,"%d",*ptrT2);
  Label37->Caption=str;
  sprintf(str,"%d",*ptrT3);
  Label38->Caption=str;

  sprintf(str,"%d",*ptrF);
  Label26->Caption=str;
}
//-----SAVE DATA------
void __fastcall TForm1::FileSaveClick(TObject *Sender)
{
  FILE *fp;
  char string[60];
  if(SaveDialog1->Execute())
   {
     sprintf(string,"%s",SaveDialog1->FileName);
     if((fp=fopen(string,"w"))==NULL)
     {
       Application->MessageBox("Could not open a file","error",MB_OK);
       return;
     }
   fprintf(fp,"time:%s \ndate:%s ",Label22->Caption,Label23->Caption);
   fprintf(fp,"\nSample rate: 100ms\n");
   fprintf(fp,"\nTemperature: CHANNEL ONE:\n");
   for(int i=0;i<DISPLAYLENGTH;i++)
     {
       fprintf(fp,"%d ,",(*indexT1++));
       if((indexT1-BufferForT1)>=BK)
          indexT1=BufferForT1; /*CIRCULAR BUFFER INDEX */
     }
  // CHANNEL TWO AND THREE
   fprintf(fp,"\nTemperature: CHANNEL TWO:\n");
    for(int i=0;i<DISPLAYLENGTH;i++)
     {
       fprintf(fp,"%d ,",(*indexT2++));
       if((indexT2-BufferForT2)>=BK)
          indexT2=BufferForT2;
     }
   fprintf(fp,"\nTemperature: CHANNEL THREE:\n");
    for(int i=0;i<DISPLAYLENGTH;i++)
     {
```

```
            fprintf(fp,"%d ,",(*indexT3++));
            if((indexT3-BufferForT3)>=BK)
               indexT3=BufferForT3;
         }
      fprintf(fp,"\nFlowRate:\n");
      for(int i=0;i<DISPLAYLENGTH;i++)
         {
            fprintf(fp,"%d ,",(*indexF++));
            if((indexF-BufferForF)>=BK)
               indexF=BufferForF;   /*CIRCULAR BUFFER INDEX*/
         }
      fclose(fp);
      }
}

//------SHOW THE RELATED INFORMATION ABOUT THE PRODUCT-----
void __fastcall TForm1::AboutClick(TObject *Sender)
{
   Form3 = new TForm3(Application);
   Form3->ShowModal();
   delete Form3;
}

//----START PUMP MANUALLY ------------------------
void __fastcall TForm1::StartPumpClick(TObject *Sender)
{
   PumpFlag=1;
   unsigned short rate;
   Form2 = new TForm2(Application);
   Form2->ShowModal();
    rate=(unsigned short)StrToFloat(Form2->ComboBox1->Text);
   /*THE MAXIMUM SPEED OF THE PUMP IS 500 STROKES PER MINUTE*/
   if((rate<=200)&(rate>0))
   {
     Timer3->Interval=(int)(30000/rate);  /*CALCULATE THE PERIOD OF THE WAVE*/
     BITNUM=0;
     BITVALUE=0;
     Timer3->Enabled=true;
     Label33->Font->Color=clGreen;
     Label33->Caption="ON";
     Label35->Caption=Form2->ComboBox1->Text;
     delete Form2;
   }
   else if(rate>200)
   {
     Application->MessageBox("Maximum speed is 200SPM","error",MB_OK);
     delete Form2;
     return;
   }
}

//------GENERATE A SQUARE WAVE WITH SELECTABLE FREQUENCY----------
void __fastcall TForm1::Timer3Timer(TObject *Sender)
{  if(BITVALUE==0)
   {  BITVALUE=1;
      cbDBitOut(BOARD_NUM,FIRSTPORTA,BITNUM,BITVALUE);
```

```
    }
    else
    { BITVALUE=0;
      cbDBitOut(BOARD_NUM,FIRSTPORTA,BITNUM,BITVALUE);
    }
}
//----------STOP PUMP MANUALLY ---------------------------------

void __fastcall TForm1::StopPumpClick(TObject *Sender)
{   PumpFlag=0;
    Label33->Font->Color=clRed;
    Label33->Caption="OFF";
    Label35->Caption="000";
    Timer3->Enabled=false;
}
//---ATUOMATICALLY START PUMP------------------------------------
void TForm1::AutoStartPump(void)
{   PumpFlag=1;
    unsigned short rate=80;
    /*THE MAXIMUM SPEED OF THE PUMP IS 500 STROKES PER MINUTE*/
    Timer3->Interval=(int)(30000/rate);  /*CALCULATE THE PERIOD OF THE WAVE*/
    BITNUM=0;
    BITVALUE=0;
    Timer3->Enabled=true;
    Label33->Font->Color=clGreen;
    Label33->Caption="ON";
    Label35->Caption="80";
}

//---AUTOMATICALLY STOP PUMP---------
void TForm1::AutoStopPump(void)
{  PumpFlag=0;
   Label33->Font->Color=clRed;
   Label33->Caption="OFF";
   Label35->Caption="000";
   Timer3->Enabled=false;
}
//------- END ----------------------
```

D.3 Unit1.h

```
//---------------------------------------------------------------
#ifndef Unit1H
#define Unit1H
//---------------------------------------------------------------
#include <Classes.hpp>
#include <Controls.hpp>
#include <StdCtrls.hpp>
#include <Forms.hpp>
#include <ExtCtrls.hpp>
#include <Menus.hpp>
#include <ComCtrls.hpp>
```

```
#include <Buttons.hpp>
#include <Dialogs.hpp>
#include <stdio.h>


#define BOARD_NUM 0 // Number of A/D board as defined with InstaCal
#define ADRANGE   UNI10VOLTS      // A/D voltage range
#define LINENUMX 10
#define LINENUMY 11
#define LINENUMF 2

//DISPLAY TIME IS DISPLAYLENGTH*SAMPLERATE=100*100=10S
#define DISPLAYLENGTH 100

#define MAXT 550
#define MINT 0
#define MAXF 250
#define MINF 50

//---------------------------------------------------------------------------
class TForm1 : public TForm
{
__published:    // IDE-managed Components
   TMainMenu *MainMenu1;
   TMenuItem *File;
   TMenuItem *FileSave;
   TMenuItem *FileExit;
   TMenuItem *Display;
   TMenuItem *Control;
   TMenuItem *StartPump;
   TMenuItem *StopPump;
   TMenuItem *Help;
   TPanel *Panel1;
   TBevel *Bevel1;
   TPanel *Panel2;
   TBevel *Bevel2;
   TBevel *Bevel3;
   TBevel *Bevel4;
   TBevel *Bevel5;
   TPaintBox *PaintBox1;
   TPaintBox *PaintBox2;
   TLabel *Label1;
   TLabel *Label2;
   TLabel *Label3;
   TLabel *Label5;
   TLabel *Label6;
   TLabel *Label7;
   TLabel *Label8;
   TLabel *Label9;
   TLabel *Label10;
   TLabel *Label12;
   TLabel *Label13;
   TLabel *Label16;
   TSpeedButton *SpeedPause;
   TSpeedButton *SpeedDisplay;
   TSpeedButton *SpeedStartPump;
```

```
TSpeedButton *SpeedStopPump;
TSpeedButton *SpeedSave;
TSpeedButton *SpeedExit;
TLabel *Label17;
TImage *Image1;
TImage *Image2;
TLabel *Label18;
TImage *Image3;
TImage *Image4;
TImage *Image5;
TLabel *Label19;
TLabel *Label20;
TLabel *Label21;
TSaveDialog *SaveDialog1;
TTimer *Timer1;
TLabel *Label22;
TLabel *Label23;
TLabel *Label24;
TLabel *Label25;
TLabel *Label26;
TMenuItem *StartDisplay;
TMenuItem *PauseDisplay;
TMenuItem *About;
TTimer *Timer2;
TLabel *Label27;
TLabel *Label28;
TLabel *Label29;
TLabel *Label30;
TTimer *Timer3;
TLabel *Label32;
TImage *Image6;
TLabel *Label33;
TLabel *Label34;
TImage *Image7;
TLabel *Label35;
TLabel *Label36;
TLabel *Label40;
TLabel *Label41;
TLabel *Label42;
TImage *Image8;
TImage *Image9;
TLabel *Label37;
TLabel *Label38;
TLabel *Label39;
TLabel *Label43;
TLabel *Label44;
TLabel *Label45;
TLabel *Label46;
TLabel *Label47;
TLabel *Label48;
TLabel *Label4;
TLabel *Label11;
TLabel *Label31;
TLabel *Label49;
TLabel *Label50;
TLabel *Label51;
```

```
    TCheckBox *CheckBox1;
    TComboBox *ComboBox1;
    TComboBox *ComboBox2;
    TLabel *Label14;
    TLabel *Label15;
    void __fastcall Paint1(TObject *Sender);
    void __fastcall Paint2(TObject *Sender);
    void __fastcall Timer1Timer(TObject *Sender);

    void __fastcall Timer2Timer(TObject *Sender);
    void __fastcall FileExitClick(TObject *Sender);
    void __fastcall StartDisplayClick(TObject *Sender);
    void __fastcall PauseDisplayClick(TObject *Sender);

    void __fastcall FileSaveClick(TObject *Sender);

    void __fastcall AboutClick(TObject *Sender);
    void __fastcall StartPumpClick(TObject *Sender);

    void __fastcall Timer3Timer(TObject *Sender);
    void __fastcall StopPumpClick(TObject *Sender);
private: // User declarations
    POINT T1Points[DISPLAYLENGTH];
    POINT T2Points[DISPLAYLENGTH];
    POINT T3Points[DISPLAYLENGTH];
    POINT FPoints[DISPLAYLENGTH];
    unsigned char PumpFlag;

public:         // User declarations
    __fastcall TForm1(TComponent* Owner);
    void drawlines(void);
    void prepare_data_for_display(TPaintBox *PP,int flag);
    void display_data(TPaintBox *PP,int flag);
    void read_data(void);
    void tracking_data(void);
    void converttostr(void);
    void AutoStartPump(void);
    void AutoStopPump(void);
};
//---------------------------------------------------------------------------
extern PACKAGE TForm1 *Form1;
//---------------------------------------------------------------------------
#endif
```

D.4 PumpSpeed.cpp

```
//---------------------------------------------------------------------------
#include <vcl.h>
#pragma hdrstop

#include "PumpSpeed.h"
//---------------------------------------------------------------------------
#pragma package(smart_init)
```

```
#pragma resource "*.dfm"
TForm2 *Form2;
//---------------------------------------------------------------------------
__fastcall TForm2::TForm2(TComponent* Owner)
   : TForm(Owner)
{
}
//---------------------------------------------------------------------------
void __fastcall TForm2::Button1Click(TObject *Sender)
{
   Close();

}
//---------------------------------------------------------------------------
```

D.5 PumpSpeed.h

```
//---------------------------------------------------------------------------
#ifndef PumpSpeedH
#define PumpSpeedH
//---------------------------------------------------------------------------
#include <Classes.hpp>
#include <Controls.hpp>
#include <StdCtrls.hpp>
#include <Forms.hpp>
//---------------------------------------------------------------------------
class TForm2 : public TForm
{
__published:	// IDE-managed Components
   TGroupBox *GroupBox1;
   TButton *Button1;
   TComboBox *ComboBox1;
   void __fastcall Button1Click(TObject *Sender);
private: // User declarations
public:		// User declarations
   __fastcall TForm2(TComponent* Owner);
};
//---------------------------------------------------------------------------
extern PACKAGE TForm2 *Form2;
//---------------------------------------------------------------------------
#endif
```

Vita Auctoris

Fang Chen received her Bachelor's degree in Electrical Engineering from Central South University of Technology in P.R. China. She joined Yueyan Paper & Pulp Group as an Electrical engineer and was responsible for designing and installing electrical control systems for Paper Making Machines. In September 2000 she commenced her study in the master program at University of Windsor, Windsor, Ontario.